

## STUDY OF FINITE DIFFERENCE METHOD IN HEAT FLOW SIMULATION OF TWO-CHAMBER THERMOS SEPARATOR MADE OF POLYPROPYLENE USING MATLAB APPLICATIONS

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**Abstract--** Heat transfer can be defined as transfer of energy from one area to another as a result of temperature differences in objects. This indicates heat transfer not only explains how heat energy is transferred from one object to another, but can also predict the rate of heat transfer that occurs under certain conditions. In this case, what is related to the heat flow model equation is two-chamber thermos separator where the separator is made of polypropylene. This separator functions to prevent the flow of heat from one side to the other side of the thermos tube. Polypropylene is included in the insulator category, although heat transfer still occurs. The heat transfer will be calculated using the finite difference method in parabolic partial differential equations using the Matlab application. The heat transfer process is assumed to occur by conduction, with a separator length of 1 cm. Assume the first side of the divider has a right temperature of 100°C, and the other side 20°C. The temperature point measured on the separator is located in the center of the separator. After completing the solution using the Matlab application with the finite difference method, a heat transfer flow simulation was obtained in the two-chamber thermos separator which shows the heat flow transfer at any time. At 0.1 seconds the temperature at T1 is 2.4°C, while at 10 seconds is 65.9704°C. Then at 0.1 seconds the temperature at T4 is 0.48°C, while at 10 seconds 19.5436°C. The conclusion is in the separator of the two-chamber thermos there is significant heat flow from the side of the first tube to the other side.

**Keywords:** PDE, Finite Difference, Heat Flow, MATLAB, Polypropylene

### 1. INTRODUCTION

The transfer of energy due to changes in temperature in objects or materials is called heat transfer[1]. It shows that heat transfer not only explains how heat energy moves from one object to another, but can also predict how fast heat transfer occurs in certain conditions[2], because this energy cannot be measured or observed directly. What can be observed is the direction of movement and its influence.

In this case, the thing related to the heat flow model equation is the two-chamber flask separator with polypropylene material. Polypropylene (PP) is considered the lightest, most versatile, cheap and chemically resistant plastic[3]. This two-chamber thermos functions is to store drinking water with two types of water. The separator in this thermos serves to block the flow of heat from one side of the thermos tube to the other side of the tube. Polypropylene material has a low density, high melting point, and low thermal conductivity so that polypropylene is included in the insulator category[3]. However, heat flow will still occur.

In many mathematical models of heat flow, partial differential equations are the basis of the solution.

The goal and complexity of the problem determine the approach that will be used to solve partial differential equations[4]. In this journal the author will try to review the temperature distribution for the case of 1-dimensional heat flow in a thermos separator. The approach used is the finite difference method for parabolic partial differential equations which are solved using the Matlab application.

Matlab is software that allows mathematical calculations, data analysis, algorithm development, simulation and modeling, and visual presentation of data[5]. One of the frequently encountered problems in the field of engineering is heat transfer in a substance. As in previous research, the aim was to carry out numerical analysis of heat transfer and heat distribution processes, namely conduction and convection heat transfer[6]. The next research discusses simulating heat transfer in the middle layer of the plate. The heat equation used is solved numerically using the finite element method with a linear rectangular element shape function that has 4 nodes[7]. The next research aims to show the temperature distribution between thin plates of iron and brass metal. The aim is to determine and study the temperature distribution on two metal plates as conductor materials using the finite

difference method calculated numerically using the Matlab 2013a application[8].

Based on all these things, Matlab can be applied to simulate heat flow in a two-chamber thermos separator made from polypropylene.

**2. METHODOLOGY**

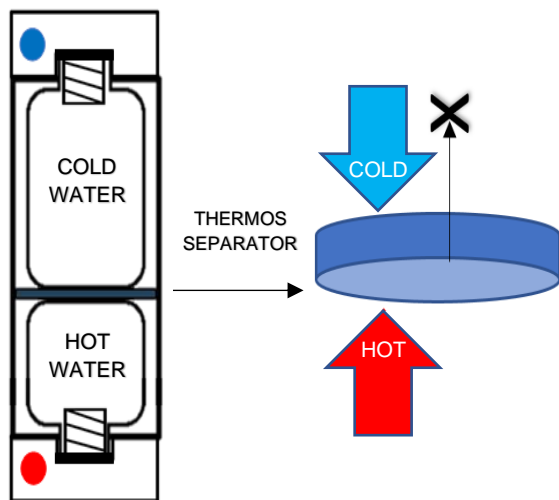
A partial differential equation is a form of equation that contains partial derivatives of one or more dependent variables for more than one independent variable of a function[9]. In science and technology, most problems can be described in the form of partial differential equations. This equation is very important to show physical conditions, where the quantities involved change temporally and spatially[10]. Partial differential equations can use finite difference methods, explicit schemes, implicit schemes, Crank-Nicholson schemes, direct integrals, variable separators, and so on[11]. In solving this case, an explicit finite difference method is used.

General form of second order linear partial differential equation:

$$A \frac{\partial^2 u}{\partial x^2} + B \frac{\partial^2 u}{\partial x \partial y} + C \frac{\partial^2 u}{\partial y^2} + Fu = G \tag{1}$$

where A, B, C, D, E, F, and G can be constants or functions to x and y. If G (x, y) is identical to zero for all x and y on the right side, equation (1) is called homogeneous. Otherwise, equation (1) is called nonhomogeneous[12].

This equation involves a derivative on one of the variables involved. For example, the temperature in a thermos separator in two 1-dimensional spaces is at a spatial x and temporal t (time), so that it is expressed by T (temperature) depending on the position of x at t.



**Figure 1.** Illustration of a two-chamber thermos separator



**Figure 2.** Illustration of heat transfer in a two-chamber thermos separator

This illustration is only 1 dimensional about the x axis and the heat flow to the center of the separator will be calculated. then an equation can be derived to predict the heat/temperature that propagates in the rod from point A to point B in a certain time interval ( $\Delta t$ )[10]. So the equation used is:

$$q(x)\Delta y\Delta z\Delta t - q(x + \Delta t)\Delta y\Delta z\Delta t = \Delta x\Delta y\Delta z\rho C\Delta T \tag{1}$$

Dividing equation (1) by the volume of the element ( $\Delta x\Delta y\Delta z$ ) and  $\Delta t$ ,

$$\frac{q(x)-q(x+\Delta t)}{\Delta x} = \rho C \frac{\Delta T}{\Delta t} \tag{2}$$

by taking the limit, we obtain the form:

$$\frac{\partial q}{\partial x} = \rho C \frac{\partial T}{\partial t} \tag{3}$$

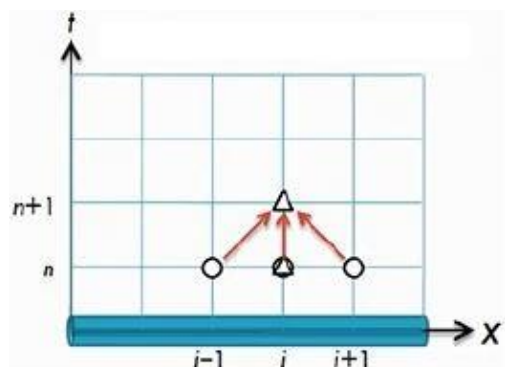
and from Fourier's law of heat conduction, the heat conduction equation is produced as follows:

$$\frac{\partial T}{\partial t} = K \frac{\partial^2 T}{\partial x^2} \tag{4}$$

where T is temperature, K is thermal coefficient, t is time and x is distance (space).

Equation (4) is a mathematical equation or model for 1-dimensional heat flow as a function of time. This equation is classified as a parabolic partial differential equation. This equation can be solved analytically or numerically. One of the methods for solving these equations is the finite difference method.

This finite difference method uses an explicit scheme. In the explicit scheme, the variable at time n+1 is calculated based on the known variable at time n.



**Figure 3.** Explicit schema grid

Using the scheme depicted in Figure 3, the variable (temperature) function  $T(x,t)$  and its derivatives in space and time can be approximated using the following form,

where the equation is:

$$\frac{T_i^{n+1}}{\Delta t} = k \left( \frac{\partial^2 T}{\partial x^2} \right) \longrightarrow \frac{T_i^{n+1} - T_i^n}{\Delta t} = k \frac{T_{i+1}^n - 2T_i^n + T_{i-1}^n}{\Delta x^2} \quad (5)$$

Then the equation is reduced to:

$$T_i^{n+1} = T_i^n + \left( k \frac{\Delta t}{\Delta x^2} \right) (T_{i+1}^n - 2T_i^n + T_{i-1}^n) \quad (6)$$

The thermal coefficient ( $k$ ) is constant along the separator and at all times. Meanwhile  $\Delta x$  is the same along the separator.

Based on the equation above, the heat transfer in the insulation will be calculated at any time using the MATLAB application. The use of the MATLAB application in this research provides advantages in terms of speed and accuracy in applying numerical methods to solve finite difference method equations.

### 3. RESULTS AND DISCUSSION

The heat transfer process is assumed to occur by conduction, with a separator length of 1 cm. Assume the first side of the divider has a right temperature of 100°C, and the other side has a temperature of 20°C. The temperature point measured on the separator is located in the center of the separator.

The heat conduction in the two-chamber thermos separator is known to have a length  $L = 1$  cm, the distance between the separator length segments  $\Delta x = 0.2$  cm, time step  $\Delta t = 0.1$  seconds, thermal diffusion coefficient in polypropylene material  $k = 0.096$  mm<sup>2</sup>/s = 0.0096 cm<sup>2</sup>/s,  $T(x=0,t) = 100^\circ\text{C}$  and  $T(x=1,t) = 20^\circ\text{C}$ , while the initial value  $T(x,t=0) = 0^\circ\text{C}$ .

After knowing the boundary conditions, heat transfer calculations are carried out in the separator using the equations in the finite difference method with an explicit scheme.

The following is the calculation on T1:

$$\begin{aligned} T_i^{n+1} &= T_i^n + \left( k \frac{\Delta t}{\Delta x^2} \right) (T_{i+1}^n - 2T_i^n + T_{i-1}^n) \\ T_1^1 &= T_1^0 + 0.024 (T_{1+1}^0 - 2T_1^0 + T_{1-1}^0) \\ T_1^1 &= 0 + 0.024 (100 - (2 \times 0) + 0) \\ T_1^1 &= 0 + 0.024 \times 100 = 2.4^\circ\text{C} \end{aligned}$$

After calculating each segment of the length of the T2, T3, and T4 separator in the first iteration or at a time of 0.1 seconds to 0.5 seconds, the following results were obtained.:

**Table 1.** The fifth iteration results

		Temperature (°C) in calculation point					
i	s	T0	T1	T2	T3	T4	T5
0	0	100	0	0	0	0	20
1	0.1	100	2.4	0	0	0.48	20
2	0.2	100	4.6848	0.0576	0.0115	0.936	20
3	0.3	100	6.8613	0.1675	0.0348	1.3722	20
4	0.4	100	8.9359	0.3250	0.0701	1.7872	20
5	0.5	100	10.914	0.5255	0.1174	2.1831	20

Next, the solution will be carried out using the MATLAB application. After entering the syntax used for solving equations using different methods up to an explicit scheme, the iteration results will come out according to what is needed.

**Table 2.** MATLAB Syntax

```
% enter boundary conditions
s = 6;
deltat = 0.1;
t = 12;
d = 0.024; % calculation results from
(k*deltat)/(deltax^2)
x = t/deltat;
T = zeros(s,x);
T(2,1) = 0;
T(3,1) = 0;
T(4,1) = 0;
T(5,1) = 0;
% processing iteration
n=0;
fprintf('\n\nIteration\t Time\t T0\t T1\t\t T2\t\t
T3\t\t T4\t\t T5\n');
% looping against time
for u=0:deltat:t-deltat
    n=n+1;
    t=0;
%looping against position
    for i=2:s-1
        T(1,n)=100;
        T(6,n)=20;
        T(i,n+1)=T(i,n)+d*(T(i+1,n)-2*T(i,n)+T(i-1,n));
    end
end

% looping against time displays images and iteration results
figure(1);
i=1:s;

for n=1:x
    fprintf('%d\t %.2f\t %d\t %f\t %f\t %f\t %f\t
%d\t\n',n-1,t,T(1,n),T(2,n),T(3,n),T(4,n),T(5,n),T(6,n));
    t=t+deltat;

    plot(i,T(i,n));
    hold on;
```

After entering the syntax in the MATLAB application and then executing the syntax, the following calculation results are obtained.

Iterasi	Maktu	T0	T1	T2	T3	T4	T5
0	0.00	100	0.000000	0.000000	0.000000	0.000000	20
1	0.10	100	2.400000	0.000000	0.000000	0.480000	20
2	0.20	100	4.684800	0.057600	0.011520	0.936960	20
3	0.30	100	6.861312	0.167547	0.034836	1.372262	20
4	0.40	100	8.935990	0.325012	0.070120	1.787230	20
5	0.50	100	10.914863	0.525558	0.117448	2.183126	20
6	0.60	100	12.803563	0.765107	0.176819	2.561154	20
7	0.70	100	14.607354	1.039911	0.248162	2.922463	20
8	0.80	100	16.331359	1.346528	0.331347	3.268140	20
9	0.90	100	17.979580	1.681794	0.426194	3.599222	20
10	1.00	100	19.556924	2.042807	0.532481	3.916688	20
11	1.10	100	21.067219	2.426898	0.649950	4.221466	20
12	1.20	100	22.514238	2.831619	0.778313	4.514435	20
13	1.30	100	23.901513	3.254722	0.917260	4.796422	20
14	1.40	100	25.232354	3.694146	1.066459	5.068208	20
(a)							
15	1.50	100	26.509860	4.147999	1.225565	5.330529	20
16	1.60	100	27.736939	4.614545	1.394223	5.580477	20
17	1.70	100	28.916315	5.092195	1.572067	5.829502	20
18	1.80	100	30.050545	5.579490	1.758728	6.067416	20
19	1.90	100	31.142026	6.075097	1.953835	6.298389	20
20	2.00	100	32.193911	6.577793	2.157015	6.522959	20
21	2.10	100	33.205614	7.086460	2.367896	6.741625	20
22	2.20	100	34.181819	7.600074	2.586111	6.954857	20
23	2.30	100	35.123494	8.117701	2.811296	7.163990	20
24	2.40	100	36.032391	8.638486	3.043093	7.366733	20
25	2.50	100	36.910160	9.161651	3.281150	7.566164	20
26	2.60	100	37.758352	9.686483	3.525122	7.761736	20
27	2.70	100	38.578426	10.212335	3.774673	7.953775	20
28	2.80	100	39.371758	10.738617	4.029476	8.142586	20
29	2.90	100	40.139640	11.264793	4.289210	8.328450	20
30	3.00	100	40.883293	11.790376	4.553566	8.511625	20
(b)							
93	9.30	100	64.613316	37.631930	22.753862	18.433380	20
94	9.40	100	64.815044	37.922410	23.007244	18.574671	20
95	9.50	100	65.014059	38.209869	23.258826	18.715260	20
96	9.60	100	65.210421	38.494345	23.508606	18.855140	20
97	9.70	100	65.404185	38.775873	23.756580	18.994299	20
98	9.80	100	65.595405	39.054489	24.002748	19.132731	20
99	9.90	100	65.784134	39.330229	24.247110	19.270426	20
100	10.00	100	65.970421	39.603128	24.489664	19.407736	20
101	10.10	100	66.154316	39.873220	24.730412	19.543574	20
102	10.20	100	66.335866	40.140539	24.969356	19.679012	20
103	10.30	100	66.515117	40.405118	25.206496	19.813684	20
104	10.40	100	66.692114	40.666991	25.441835	19.947583	20
105	10.50	100	66.866901	40.926191	25.675377	20.080703	20
106	10.60	100	67.039518	41.182748	25.907124	20.213039	20
107	10.70	100	67.210007	41.436696	26.137081	20.344584	20
(c)							

Figure 4. (a) Iterative temperature changes 0-14 (b) Iterative temperature changes 15-30 (c) Iterative temperature changes 93-107

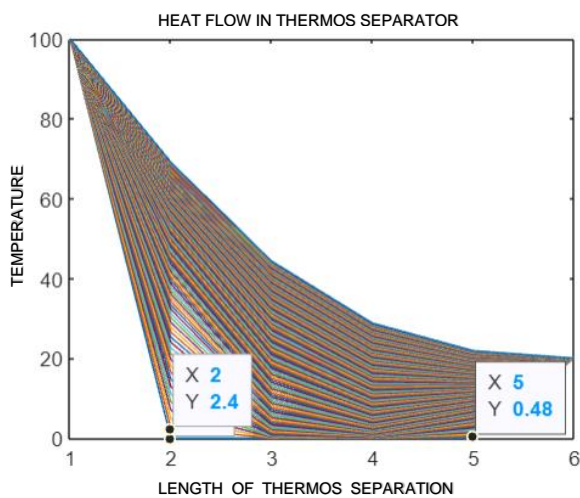


Figure 5. Temperature Changes for Each Segment at Each Time

#### 4. CONCLUSION

Based on the results of calculations and discussions using the finite difference method in the Matlab application, a simulation of the heat transfer flow in a two-chamber thermos separator was obtained which shows the heat flow transfer with a number of iterations of 107, total time of 10.7 seconds and time difference from one iteration to another is 0.1 sec.

At 0.1 second, the temperature at point T1 is 2.4°C. Meanwhile at the 10th second, the temperature at point T1 became 65.9704°C. Apart from that, at 0.1 second, the temperature at point T4 is 0.48°C. Meanwhile, in the 10th second, the temperature at point T4 becomes 19.5436°C.

So it can be concluded that in the separator in this two-chamber flask, there is significant heat flow from the first tube side to the other side of the tube.

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