

A Comparison of Implicit and Modified Implicit Finite Difference Schemes for Solving Parabolic Equations

Abstract.

This paper presents the comparison of implicit scheme and modified implicit scheme for solving parabolic partial differential equations, the modified implicit scheme is compared with the implicit scheme using its stability, local truncation error, derivation and numerical examples. Following this, it was discovered that the modified implicit scheme can be used as an alternative scheme to the implicit scheme for solving problems on parabolic partial differential equations.

Keyword: Implicit scheme, Stability, Local truncation error, Modified Implicit scheme, Parabolic Equations.

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1. Introduction

The simplest and well known heat conduction equation is the one dimensional parabolic partial differential equation called the diffusion equation. It is first order in time and second order in space. Most problem in Engineering, Physics, Fluid mechanics, Chemistry and other areas of application rely heavily on this equation.

The solutions of this type of parabolic partial differential equation can be found using analytical and numerical methods. Though, it is not all partial differential equation that can be solve analytically therefore, numerical method is mostly employed. The process of obtaining an approximate solutions which converge closely to the exact solution of a parabolic partial differential equation is called numerical method. There are different types of numerical methods that can be used to get a very good approximate results for parabolic equations but in this work, we shall restrict our method to the finite difference methods (FDM).

Finite difference method is an approximate method for solving partial differential equations. It is a numerical technique for solving differential equations by approximating derivatives with finite differences. The process requires the discretization of both the time interval and spatial domain. The process convert partial differential equations which may be non-linear into a system of linear equations that can be solved by matrix algebra. The prominent and commonly used types of finite difference methods are, *explicit scheme*, *implicit scheme*, *Crank-Nicolson scheme*. This schemes perform better than each other, mostly in terms of stability, accuracy and convergence.

Different numerical experts and researchers in Mathematics and related fields have used the finite difference methods a lot. [1] Compared the exact solution of parabolic equations with its numerical solution using modified Crank-Nicolson scheme. [2] considered a practical method for numerical solution to partial differential equations of heat conduction type. [3] Investigated the stability of Modified Crank-Nicolson scheme using Fourier method (von-Neumann method). They prove that the scheme is consistent, convergent and stable. [4] compared Crank-Nicolson scheme with modified Crank-Nicolson scheme. They show that the modified Crank-Nicolson scheme is efficient and good for solving parabolic equations. [6] modified the simple explicit scheme and prove that it is much more stable than the simple explicit case, enabling larger time steps to be used. [7] established an improved θ method to improve the θ -iterated Crank-Nicolson scheme to second order accuracy. [8] Modified the Crank-Nicolson scheme to a 3-level implicit finite difference scheme similar to the Crank-Nicolson scheme, there method utilizes an extra grid point at the lower level and the result is shown to be more accurate than the Crank-Nicolson scheme. There are lot of interesting and comprehensive texts on finite difference method, they include [9,10,11,12,13 and 14]

In this work, focus is on the implicit scheme and its modification: in terms of local truncation error, stability and also comparing the results of the schemes using numerical examples.

2. Finite Difference Approximation

For the purpose of this work, the following finite difference approximation [14, 15] are required

$$\left. \begin{aligned} \left(\frac{\partial f}{\partial t}\right)_{i,j} &= \frac{1}{k} \Delta t f_{i,j} = \frac{f_{i,j} - f_{i,j-1}}{k} + O(k) \\ \left(\frac{\partial f}{\partial t}\right)_{i,j} &= \frac{1}{k} \Delta t f_{i,j} = \frac{f_{i,j+1} - f_{i,j}}{k} + O(k) \\ \left(\frac{\partial^2 f}{\partial x^2}\right)_{i,j+1} &= \frac{1}{h^2} \delta_x^2 f_{i,j+1} = \frac{f_{i+1,j+1} - 2f_{i,j+1} + f_{i-1,j+1}}{h^2} + O(h^2) \\ \frac{\partial^2 f}{\partial x^2} &= \frac{1}{h^2} \delta_x^2 f_{i,j-1} = \frac{f_{i+1,j} - 2f_{i,j} + f_{i-1,j}}{h^2} + O(h^2) \end{aligned} \right\} \quad (1)$$

2.1 Problem Definition and Methodology

The following initial boundary value parabolic problem of the form

$$\left. \begin{aligned} \frac{1}{c^2} \frac{\partial f}{\partial t} &= \frac{\partial^2 f}{\partial x^2} \\ f(x, 0) &= f(x), \quad 0 < x < 1 \\ f(0, t) &= f(l, t) = 0 \leq t \leq l \end{aligned} \right\} \quad (2)$$

is considered. Equation (2) is typical of the heat equation with initial and boundary conditions. For the derivation of the schemes, the finite difference approximations (1) is substituted into equation (2), this is done for both the time derivative and the spatial derivatives. The derivation of both schemes is described as follows:

2.2 Implicit Scheme: the derivation

Substituting the time derivative $\frac{\partial f}{\partial t}$ in equation (2) with the finite approximation $\frac{1}{k} \Delta_t f_{i,j}$ and the second derivative $\frac{\partial^2 f}{\partial x^2}$ with the finite approximation $\frac{1}{h^2} \delta_x^2 f_{i,j+1}$ gives the following finite difference approximation

$$\frac{1}{k} \Delta_t f_{i,j} = \frac{c^2}{h^2} \delta_x^2 f_{i,j+1}$$

which is analogue to equation (2). Solving further gives

$$f_{i,j} = -r (f_{i+1,j+1} + f_{i-1,j+1}) + (1 + 2r)f_{i,j+1} \quad (3)$$

Equation (3) is the implicit scheme, where $r = \frac{kc^2}{h^2}$ and it can be written in matrix form $Af = a$, defined as follows:

$$\begin{bmatrix} 1 + 2r & -r & \cdots & & \\ -r & 1 + 2r & -r & \cdots & \\ & -r & 1 + 2r & \ddots & \\ \vdots & \vdots & \ddots & \ddots & -r \\ & & & -r & 1 + 2r \end{bmatrix} \begin{bmatrix} f_{1,j} \\ f_{2,j} \\ f_{3,j} \\ \vdots \\ f_{n,j} \end{bmatrix} = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_n \end{bmatrix}$$

2.3 Modified Implicit scheme: the derivation

The spatial and time derivatives in equation (2) is replaced with the following finite difference approximations $\frac{1}{h^2} \delta_x^2 f_{i,j-1}$ and $\frac{1}{k} \Delta_t f_{i,j}$ respectively, then the finite difference analogue to equation (2) becomes

$$\frac{1}{k} \Delta_t f_{i,j} = \frac{c^2}{h^2} \delta_x^2 f_{i,j-1}$$

solving further gives

$$f_{i,j-1} = -r (f_{i+1,j} + f_{i-1,j}) + (1 + 2r)f_{i,j} \quad (4)$$

Equation (4) is the modified implicit scheme. where $r = \frac{c^2 k}{h^2}$ and it can be written in matrix form $Af = b$, defined as follows:

$$\begin{bmatrix} 1 + 2r & -r & \cdots & & \\ -r & 1 + 2r & -r & \cdots & \\ & -r & 1 + 2r & \ddots & \\ \vdots & \vdots & \ddots & \ddots & -r \\ & & & -r & 1 + 2r \end{bmatrix} \begin{bmatrix} f_{1,j-1} \\ f_{2,j-1} \\ f_{3,j-1} \\ \vdots \\ f_{n,j-1} \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ \vdots \\ b_n \end{bmatrix}$$

2.4 Local Truncation error

The local truncation error of the implicit scheme can be found [10], [11] and [12]. We derive below the local truncation error of the modified Implicit scheme.

2.4.1 Modified Implicit scheme (Local truncation error)

Considering the parabolic partial differential equation (2) given as

$$\frac{\partial f}{\partial t} = \frac{\partial^2 f}{\partial x^2},$$

and the finite difference approximation by

$$\frac{f_{i,j} - f_{i,j-1}}{k} = \frac{f_{i+1,j} - 2f_{i,j} + f_{i-1,j}}{h^2} \quad (5)$$

If the approximation (5) equals $F_{i,j}(f)$ such that

$$F_{i,j}(f) = \frac{f_{i,j} - f_{i,j-1}}{k} - \frac{f_{i+1,j} - 2f_{i,j} + f_{i-1,j}}{h^2}$$

also, if $T_{i,j} = f_{i,j}(\tilde{f})$ where $f_{i,j}(\tilde{f})$ is the error, so we have

$$T_{i,j} = f_{i,j}(\tilde{f}) = \frac{\tilde{f}_{i,j} - \tilde{f}_{i,j-1}}{k} - \frac{\tilde{f}_{i+1,j} - 2\tilde{f}_{i,j} + \tilde{f}_{i-1,j}}{h^2} \quad (6)$$

using Taylor's expansion and substituting into equation (6) we have

$$\begin{aligned} & \frac{1}{k} \left[\tilde{f}_{i,j} - \left(\tilde{f}_{i,j} - k \left(\frac{\partial \tilde{f}}{\partial t} \right) - \frac{1}{2} k^2 \left(\frac{\partial^2 \tilde{f}}{\partial t^2} \right) - \frac{1}{6} k^3 \left(\frac{\partial^3 \tilde{f}}{\partial t^3} \right) - \frac{1}{24} k^4 \left(\frac{\partial^4 \tilde{f}}{\partial t^4} \right) - \dots \right) \right] \\ & - \frac{1}{h^2} \left[\tilde{f}_{i,j} + \left(\tilde{f}_{i,j} + h \left(\frac{\partial \tilde{f}}{\partial x} \right) + \frac{1}{2} h^2 \left(\frac{\partial^2 \tilde{f}}{\partial x^2} \right) + \frac{1}{6} h^3 \left(\frac{\partial^3 \tilde{f}}{\partial x^3} \right) + \frac{1}{24} h^4 \left(\frac{\partial^4 \tilde{f}}{\partial x^4} \right) + \dots \right) \right] \\ & \frac{1}{h^2} \left[-2\tilde{f}_{i,j} + \tilde{f}_{i,j} - h \left(\frac{\partial \tilde{f}}{\partial x} \right) + \frac{1}{2} h^2 \left(\frac{\partial^2 \tilde{f}}{\partial x^2} \right) - \frac{1}{6} h^3 \left(\frac{\partial^3 \tilde{f}}{\partial x^3} \right) + \frac{1}{24} h^4 \left(\frac{\partial^4 \tilde{f}}{\partial x^4} \right) - \dots \right] \end{aligned}$$

by cancelation of opposite signs, we obtain

$$T_{i,j} = \frac{\partial \tilde{f}}{\partial t} - \frac{\partial^2 \tilde{f}}{\partial x^2} + \frac{1}{2} k^2 \frac{\partial^2 \tilde{f}}{\partial t^2} - \frac{1}{12} h^2 \frac{\partial^4 \tilde{f}}{\partial x^4} + \dots$$

since \tilde{f} is the exact solution of $\frac{\partial f}{\partial t} = \frac{\partial^2 f}{\partial x^2}$ then $\frac{\partial \tilde{f}}{\partial t} - \frac{\partial^2 \tilde{f}}{\partial x^2} = 0$ therefore the non-zero part of the local truncation error is

$$\frac{1}{2} k \frac{\partial^2 \tilde{f}}{\partial t^2} - \frac{1}{12} h^2 \frac{\partial^4 \tilde{f}}{\partial x^4} \quad (7)$$

therefore,

$$T_{i,j} = \left(\frac{1}{2}k \frac{\partial^2 \tilde{f}}{\partial t^2} - \frac{1}{12}h^2 \frac{\partial^4 \tilde{f}}{\partial x^4} \right) + \dots \quad (8)$$

such that $\phi_1 k - \phi_2 h^2 \in O(k + h^2)$, where $\phi_1 = \frac{1}{2} \frac{\partial^2 \tilde{f}}{\partial t^2}$, and $\phi_2 = \frac{1}{12} \frac{\partial^4 \tilde{f}}{\partial x^4}$ hence $T_{i,j} \in O(k + h^2)$. This shows that the local truncation error of the modified Implicit approximation is $O(k + h^2)$.

2.5 Stability of Implicit scheme by von-Neumann Method

The stability of the Implicit scheme using the von-Neumann method is verify as follows:

Considering the approximation

$$f_{i,j} = -r(f_{i-1,j+1} + f_{i+1,j+1}) + (1 + 2r)f_{i,j+1}$$

Given the finite difference approximation solution in separable form as

$$\zeta_{i,j} = \xi^{\gamma i h} \zeta^{z\beta j k} = \xi^{\gamma i h + z\beta j k} \quad (9)$$

In equation (9) we let $\gamma(\beta) = \gamma$, let $\xi = \zeta^{\gamma h}$ be the amplification factor, so that equation (9) becomes

$$\zeta_{i,j} = \xi^i \zeta^{z\beta j k} \quad (10)$$

substituting equation (10) into equation (3) gives

$$\begin{aligned} \xi^i \zeta^{z\beta j k} &= -r(\xi^{i+1} \zeta^{z\beta(j-1)k} + \xi^{i+1} \zeta^{z\beta(j+1)k}) + (1 + 2r)\xi^{i+1} \zeta^{z\beta j k} \\ \xi^i \zeta^{z\beta j k} &= -r\xi^i \zeta^{z\beta j k} (\xi \zeta^{-z\beta k} + \xi \zeta^{z\beta k}) + (1 + 2r)\xi \zeta^{z\beta j k} \end{aligned}$$

dividing both sides by $\xi^i \zeta^{z\beta j k}$ we get

$$1 = -r(\xi \zeta^{-z\beta k} + \xi \zeta^{z\beta k}) + (1 + 2r)\xi$$

which can be written as

$$1 = [-r(\zeta^{-z\beta k} + \zeta^{z\beta k}) + (1 + 2r)] \xi \quad (11)$$

using the following trigonometric Identities

$$\left. \begin{aligned} \zeta^{-z\beta k} + \zeta^{z\beta k} &= 2 \cos \beta k \\ \text{and} \\ 2 \sin^2 \left(\frac{\beta k}{2} \right) &= 1 - \cos \beta k \end{aligned} \right\} \quad (12)$$

in equation (11) we get

$$[-r(2 \cos \beta k) + (1 + 2r)] \xi = 1$$

which gives

$$\left[1 + 4r \sin^2 \left(\frac{\beta k}{2} \right) \right] \xi = 1$$

and therefore

$$\xi = \left[\frac{1}{1 + 4r \sin^2 \left(\frac{\beta k}{2} \right)} \right]$$

showing that $|\xi| \leq 1$ for all values of r and therefore the implicit approximation is unconditionally stable.

2.6 Stability of Modified Implicit Scheme by von-Newmann method

For the stability of modified Implicit scheme by von-Newmann, see [5] but for the purpose of this paper and after substituting the trigonometric identities, we have that:

$$\begin{aligned} \xi^{-1} &= (1 + 2r) - r(2 \cos \beta k) = 1 + 2r(1 - \cos \beta k) \\ \xi^{-1} &= \left[1 + 4r \sin^2 \left(\frac{\beta k}{2} \right) \right] \\ \xi &= \frac{1}{\left[1 + 4r \sin^2 \left(\frac{\beta k}{2} \right) \right]} \end{aligned} \tag{13}$$

from equation (13), it is apparent that $|\xi| \leq 1$ for all values of r , and therefore, the modified implicit scheme is unconditionally stable.

Numerical examples

For clarity and numerical comparison, the following parabolic partial differential equation is considered for $h = 0.1$, $r = 0.05$.

Example 1:

$$\left. \begin{aligned} &\frac{\partial f}{\partial t} = \frac{\partial^2 f}{\partial x^2}, \quad 0 \leq x \leq 1 \\ &\text{with initial condition} \quad f(x, 0) = \sin(\pi x), \quad 0 < x < 1 \\ &\text{and boundary condition} \quad f(0, t) = f(l, t) = 0 \leq t \leq l \end{aligned} \right\} \tag{14}$$

Solution

solution of problems (14) using equation both the Implicit and modified Implicit schemes gives the following tri-diagonal matrix for $1 \leq i \leq 9$ at $j = 1$, we get a

tridiagonal matrix which is represented below;

$$\begin{bmatrix}
 1.1 & -0.05 & & & & & & & \\
 -0.05 & 1.1 & -0.05 & & & & & & \\
 & -0.05 & 1.1 & -0.05 & & & & & \\
 & & -0.05 & 1.1 & -0.05 & & & & \\
 & & & -0.05 & 1.1 & -0.05 & & & \\
 & & & & -0.05 & 1.1 & -0.05 & & \\
 & & & & & -0.05 & 1.1 & -0.05 & \\
 & & & & & & -0.05 & 1.1 & -0.05 \\
 & & & & & & & -0.05 & 1.1
 \end{bmatrix}
 \begin{bmatrix}
 f_{1,1} \\
 f_{2,1} \\
 f_{3,1} \\
 f_{4,1} \\
 f_{5,1} \\
 f_{6,1} \\
 f_{7,1} \\
 f_{8,1} \\
 f_{9,1}
 \end{bmatrix}
 =
 \begin{bmatrix}
 0.3090 \\
 0.5878 \\
 0.8090 \\
 0.9511 \\
 1.0000 \\
 0.9511 \\
 0.8090 \\
 0.5878 \\
 0.3090
 \end{bmatrix}$$

table 1 present the results of example 1 above using the Implicit scheme with computation at $1 \leq i \leq 9$, and $0 \leq j \leq 8$

Table 1: table of results at $k = 0.0005$, $r = 0.05$ and $h = 0.1$

t	x	j	$f_{1, j}$	$f_{2, j}$	$f_{3, j}$	$f_{4, j}$	$f_{5, j}$	$f_{6, j}$	$f_{7, j}$	$f_{8, j}$	$f_{9, j}$
0.0005	0.1	0	0.3075	0.3060	0.3045	0.3030	0.3015	0.3000	0.2986	0.2972	0.2958
0.001	0.2	1	0.5895	0.5821	0.5793	0.5765	0.5737	0.5709	0.5681	0.5653	0.5625
0.0015	0.3	2	0.8051	0.8012	0.7973	0.7934	0.7895	0.7857	0.7819	0.7781	0.7743
0.002	0.4	3	0.9465	0.9419	0.9373	0.9327	0.9282	0.9237	0.9192	0.9147	0.9102
0.0025	0.5	4	0.9951	0.9903	0.9855	0.9807	0.9759	0.9712	0.9665	0.9618	0.9571
0.003	0.6	5	0.9465	0.9419	0.9373	0.9327	0.9282	0.9237	0.9192	0.9147	0.9102
0.0035	0.7	6	0.8051	0.8012	0.7973	0.7934	0.7895	0.7857	0.7819	0.7781	0.7743
0.004	0.8	7	0.5849	0.5821	0.5793	0.5765	0.5737	0.5709	0.5681	0.5653	0.5625
0.0045	0.9	8	0.3075	0.3060	0.3045	0.3030	0.3015	0.3000	0.2986	0.2972	0.2958

Table 2: table of results at $k = 0.0005$, $r = 0.05$ and $h = 0.1$

t	x	j	$f_{1, j}$	$f_{2, j}$	$f_{3, j}$	$f_{4, j}$	$f_{5, j}$	$f_{6, j}$	$f_{7, j}$	$f_{8, j}$	$f_{9, j}$
0.0005	0.1	1	0.3075	0.3060	0.3045	0.3030	0.3015	0.3000	0.2986	0.2972	0.2958
0.001	0.2	2	0.5895	0.5821	0.5793	0.5765	0.5737	0.5709	0.5681	0.5653	0.5625
0.0015	0.3	3	0.8051	0.8012	0.7973	0.7934	0.7895	0.7857	0.7819	0.7781	0.7743
0.002	0.4	4	0.9465	0.9419	0.9373	0.9327	0.9282	0.9237	0.9192	0.9147	0.9102
0.0025	0.5	5	0.9951	0.9903	0.9855	0.9807	0.9759	0.9712	0.9665	0.9618	0.9571
0.003	0.6	6	0.9465	0.9419	0.9373	0.9327	0.9282	0.9237	0.9192	0.9147	0.9102
0.0035	0.7	7	0.8051	0.8012	0.7973	0.7934	0.7895	0.7857	0.7819	0.7781	0.7743
0.004	0.8	8	0.5849	0.5821	0.5793	0.5765	0.5737	0.5709	0.5681	0.5653	0.5625
0.0045	0.9	9	0.3075	0.3060	0.3045	0.3030	0.3015	0.3000	0.2986	0.2972	0.2958

table 2 presents the result of example 1 above using the modified Implicit scheme, with computation at $1 \leq i \leq 9$, and $1 \leq j \leq 9$

Example 2.

Compare the solution of the following parabolic partial differential equation using Implicit and modified Implicit scheme for $h = 1$.

$$\left. \begin{aligned}
 & \frac{1}{4} \frac{\partial f}{\partial t} = \frac{\partial^2 f}{\partial x^2}, \\
 & \text{with initial condition} \\
 & f(x, 0) = \left(\frac{8x-x^2}{2} \right), \\
 & \text{and boundary condition} \\
 & f(0, t) = f(8, t) = 0
 \end{aligned} \right\} (15)$$

Solution:

in example 2 above, we have that $t = \frac{1}{8}$, $c^2 = 4$ such that $r = 0.5$ solving the parabolic partial differential equation above results into the following tri-diagonal

matrix:

$$\begin{bmatrix} 2 & -0.5 & & & & & & \\ -0.5 & 2 & -0.5 & & & & & \\ & -0.5 & 2 & -0.5 & & & & \\ & & -0.5 & 2 & -0.5 & & & \\ & & & -0.5 & 2 & -0.5 & & \\ & & & & -0.5 & 2 & -0.5 & \\ & & & & & -0.5 & 2 & \\ & & & & & & -0.5 & 2 \end{bmatrix} \begin{bmatrix} f_{1,1} \\ f_{2,1} \\ f_{3,1} \\ f_{4,1} \\ f_{5,1} \\ f_{6,1} \\ f_{7,1} \end{bmatrix} = \begin{bmatrix} 3.5000 \\ 6.0000 \\ 7.5000 \\ 8.0000 \\ 7.5000 \\ 6.0000 \\ 3.5000 \end{bmatrix}$$

table 3 shows the result of the Implicit scheme for example 2, which is compute at $1 \leq i \leq 7$, and $0 \leq j \leq 6$.

Table 3: table of results at $k = 0.125$, $r = 0.5$ and $h = 1$

t	x	j	$f_{1, j}$	$f_{2, j}$	$f_{3, j}$	$f_{4, j}$	$f_{5, j}$	$f_{6, j}$	$f_{7, j}$
0.125	1	0	3.1340	5.5361	7.0103	7.5052	7.0103	5.5361	3.1340
0.25	2	1	2.8456	5.1143	6.5393	7.0222	6.5393	5.1143	2.8456
0.375	3	2	2.6057	4.7315	6.0918	6.5570	6.0918	4.7315	2.6057
0.5	4	3	2.3986	4.3829	5.6700	6.1135	5.6700	4.3829	2.3986
0.625	5	4	2.2153	4.0639	5.2745	5.6940	5.2745	4.0639	2.2153
0.75	6	5	2.0503	3.7707	4.9048	5.2994	4.9048	3.7707	2.0503
0.875	7	6	1.9002	3.5004	4.5599	4.9297	4.5599	3.5004	1.9002

table 4 present the result of the modified Implicit scheme for example 2, with computation at $1 \leq i \leq 7$, and $1 \leq j \leq 7$

Table 4: table of results at $k = 0.125$, $r = 0.5$ and $h = 1$

t	x	j	$f_{1, j}$	$f_{2, j}$	$f_{3, j}$	$f_{4, j}$	$f_{5, j}$	$f_{6, j}$	$f_{7, j}$
0.125	1	1	3.1340	5.5361	7.0103	7.5052	7.0103	5.5361	3.1340
0.25	2	2	2.8456	5.1143	6.5393	7.0222	6.5393	5.1143	2.8456
0.375	3	3	2.6057	4.7315	6.0918	6.5570	6.0918	4.7315	2.6057
0.5	4	4	2.3986	4.3829	5.6700	6.1135	5.6700	4.3829	2.3986
0.625	5	5	2.2153	4.0639	5.2745	5.6940	5.2745	4.0639	2.2153
0.75	6	6	2.0503	3.7707	4.9048	5.2994	4.9048	3.7707	2.0503
0.875	7	7	1.9002	3.5004	4.5599	4.9297	4.5599	3.5004	1.9002

Disussion

From the comparison above, it can be deduced that the modified Implicit scheme is good and efficient for solving parabolic partial differential equations. The results of the local truncation error shows that the modified implicit scheme has the same order $O(k + h^2)$ as the implicit scheme, and the stability proof confirms that the amplification factor $|\xi| \leq 1$ for all values of r , which shows that the modified implicit scheme is unconditionally stable. Also, from the numerical computations, it is observed that the computation for the next step for the implicit scheme starts from $j = 0$ while that of the modified Implicit scheme starts from $j = 1$ but produces the same results at the different stages, also, the step $j = 1$ for the implicit scheme produces same results for the step $j = 2$ for the modified implicit scheme and same as other steps.

Conclusion

From the results above, it is clear that the modified implicit scheme is fast and effective for solving parabolic equations (heat equations) since, it also require solving a tri-diagonal matrix at every level. We therefore conclude that the modified implicit scheme can be use as alternative scheme to the implicit scheme for solving the heat equations.

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