AM5630: Foundations of Computational Fluid Dynamics
Computer Assignment 2

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1 Problem 1: 2D Transient Heat Conduction Equation

1.1 Problem Definition

Dimensions:

Number of X grid points : 31

Number of Y grid points : 41

Thermal Conductivity (K) : 380 W/m^0C

Thermal Diffusivity (α):11.234*10$^-5$ m^2/s

Length (l) : 0.3m

Width (w) : 0.4m

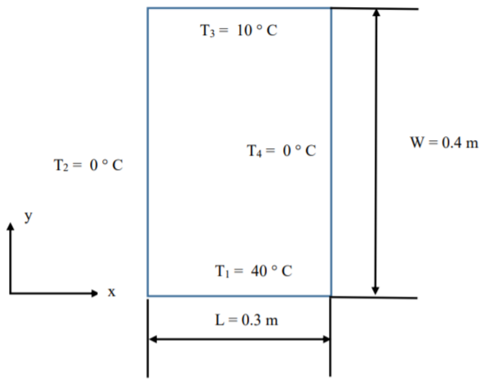


Figure 1: Computational domain of rectangular bar with boundary conditions

The Governing equation for 2D Unsteady Heat Conduction is :

$$\frac{\partial T}{\partial t} = \alpha * (\frac{\partial T^2}{\partial x^2} + \frac{\partial T^2}{\partial y^2}); \tag{1}$$

This is a Parabolic Partial Differential Equation

1.2 Numerical Formulation

- *FTCS*

  The Finite difference scheme (FTCS) used to solve the 2D Unsteady Heat Conduction equation is an explicit method.

  The given parabolic PDE can be discretized as follows using FTCS Scheme:

$$\frac{\partial T}{\partial t} = \alpha * (\frac{\partial T^2}{\partial x^2} + \frac{\partial T^2}{\partial y^2}); \tag{2}$$

$$\frac{T_{i,j}^{n+1} - T_{i,j}^{n}}{\triangle t} = \alpha * \frac{T_{i+1,j}^{n} - 2 * T_{i,j}^{n} + T_{i-1,j}^{n}}{\triangle x^2} + \alpha * \frac{T_{i,j+1}^{n} - 2 * T_{i,j}^{n} + T_{i,j-1}^{n}}{\triangle y^2}$$

$$T_{i,j}^{n+1} - T_{i,j}^{n} = \nu_x * (T_{i+1,j}^{n} - 2 * T_{i,j}^{n} + T_{i-1,j}^{n}) + \nu_y * (T_{i,j+1}^{n} - 2 * T_{i,j}^{n} + T_{i,j-1}^{n}) \tag{3}$$

  Where :

$$\nu_x = \frac{\alpha * \triangle t}{\triangle x^2} \quad \nu_y = \frac{\alpha * \triangle t}{\triangle y^2}$$

- *ADI*

  The Finite difference scheme used to solve the 2D Unsteady Heat Conduction equation is ADI Scheme (Alternating Direction Implicit Method).

$$\frac{T_{i,j}^{n+\frac{1}{2}} - T_{i,j}^{n}}{\frac{\triangle t}{2}} = \alpha * \frac{T_{i+1,j}^{n+\frac{1}{2}} - 2 * T_{i,j}^{n+\frac{1}{2}} + T_{i-1,j}^{n+\frac{1}{2}}}{\triangle x^2} + \alpha * \frac{T_{i,j+1}^{n} - 2 * T_{i,j}^{n} + T_{i,j-1}^{n}}{\triangle y^2} \tag{4}$$

$$\frac{T_{i,j}^{n+1} - T_{i,j}^{n+\frac{1}{2}}}{\frac{\triangle t}{2}} = \alpha * \frac{T_{i+1,j}^{n+\frac{1}{2}} - 2 * T_{i,j}^{n+\frac{1}{2}} + T_{i-1,j}^{n+\frac{1}{2}}}{\triangle x^2} + \alpha * \frac{T_{i,j+1}^{n+1} - 2 * T_{i,j}^{n+1} + T_{i,j-1}^{n+1}}{\triangle y^2} \tag{5}$$

$$-\gamma_x T_{i+1,j}^{n+\frac{1}{2}} + (1 + 2\gamma_x) T_{i,j}^{n+\frac{1}{2}} - \gamma_x T_{i-1,j}^{n+\frac{1}{2}} = (1 - 2\gamma_y) T_{i,j}^{n} + \gamma_y T_{i,j+1}^{n} + \gamma_y T_{i,j-1}^{n} \tag{6}$$

$$-\gamma_y T_{i,j+1}^{n+1} + (1 + 2\gamma_y) T_{i,j}^{n+1} - \gamma_y T_{i,j-1}^{n+1} = \gamma_x T_{i+1,j}^{n+\frac{1}{2}} + (1 + 2\gamma_x) T_{i,j}^{n+\frac{1}{2}} + \gamma_x T_{i-1,j}^{n+\frac{1}{2}} \tag{7}$$

where:

$$\gamma_x = \frac{\alpha * \triangle t}{2 * \triangle x^2} \quad \gamma_y = \frac{\alpha * \triangle t}{2 * \triangle y^2}$$

2 Problem 2: 2D Steady State Heat Conduction Equation

2.1 Problem Definition

The same computational domain is used for discretization to solve the steady state equation.

The Governing equation for 2D Unsteady Heat Conduction is :

$$\frac{\partial T^2}{\partial x^2} + \frac{\partial T^2}{\partial y^2} = 0;$$

This is an Elliptic Partial Differential Equation

2.2 Numerical Formulation

- Point Gauss Seidal Method
  - The given elliptic PDE is discretized as follows using Point Gauss Seidal Method

$$T_{i,j}^{k+1} = \frac{1}{2(1+\beta^2)} * (T_{i+1,j}^{k} + T_{i-1,j}^{k+1} + \beta^2(T_{i,j+1}^{k} + T_{i,j-1}^{k+1})) \tag{8}$$

- Line Gauss Seidal Method
  - The given elliptic PDE is discretized as follows using Line Gauss Seidal Method

$$T_{i-1,j}^{k+1} - 2(1+\beta^2)T_{i,j}^{k+1} + T_{i+1,j}^{k+1} = -\beta^2 T_{i,j+1}^{k} - \beta^2 T_{i,j-1}^{k+1} \tag{9}$$

- PSOR Method
  - The given elliptic PDE is discretized as follows using PSOR Method

$$T_{i,j}^{k+1} = (1-\omega)T_{i,j}^{k} + \frac{\omega}{2(1+\beta^2)} * (T_{i+1,j}^{k} + T_{i-1,j}^{k+1} + \beta^2(T_{i,j+1}^{k} + T_{i,j-1}^{k} \tag{10}$$

- LSOR Method
  - The given elliptic PDE is discretized as follows using LSOR Method

$$\omega T_{i-1,j}^{k+1} - 2(1+\beta^2)T_{i,j}^{k+1} = -(1-\omega) * (2(1+\beta^2)T_{i,j}^{k}) - \omega * \beta^2 * (T_{i,j+1}^{k} + T_{i,j-1}^{k+1}) \tag{11}$$

- ADI Method
  - The given elliptic PDE is discretized as follows using ADI Method

$$T_{i-1,j}^{k+\frac{1}{2}} - 2(1+\beta^2)T_{i,j}^{k+\frac{1}{2}} + T_{i+1,j}^{k+\frac{1}{2}} = -T_{i,j-1}^{k} - T_{i,j+1}^{k} \tag{12}$$

$$T_{i,j-1}^{k+1} - 2(1+\beta^2)T_{i,j}^{k+1} + T_{i,j+1}^{k+1} = -T_{i-1,j}^{k+\frac{1}{2}} - T_{i+1,j}^{k+\frac{1}{2}} \tag{13}$$

where

$$\beta = \frac{\triangle x}{\triangle y}$$

$$\omega = Relaxation Factor$$

3 Problem 3: Effect of Symmetry

3.1 Problem Definition

The same computational domain is used for discretization to solve the steady state equation.

The Governing equation for 2D Unsteady Heat Conduction is :

$$\frac{\partial T^2}{\partial x^2} + \frac{\partial T^2}{\partial y^2} = 0;$$

This is an Elliptic Partial Differential Equation

Case 1: *The Most effective method obtained from problem 2 must be employed to a changed boundary conditions for the same computational domain.*
Case 2: *The same method to be applied to a reduced computational domain of a quadrant*

3.2 Numerical Formulation

- PSOR Method
  - The given elliptic PDE is discretized as follows using PSOR Method

$$T_{i,j}^{k+1} = (1-\omega)T_{i,j}^{k} + \frac{\omega}{2(1+\beta^2)} * (T_{i+1,j}^{k} + T_{i-1,j}^{k+1} + \beta^2(T_{i,j+1}^{k} + T_{i,j-1}^{k} \tag{14}$$

- LSOR Method
  - The given elliptic PDE is discretized as follows using LSOR Method

$$\omega T_{i-1,j}^{k+1} - 2(1+\beta^2)T_{i,j}^{k+1} = -(1-\omega) * (2(1+\beta^2)T_{i,j}^{k}) - \omega * \beta^2 * (T_{i,j+1}^{k} + T_{i,j-1}^{k+1}) \tag{15}$$

- ADI Method
  - The given elliptic PDE is discretized as follows using ADI Method

$$T_{i-1,j}^{k+\frac{1}{2}} - 2(1+\beta^2)T_{i,j}^{k+\frac{1}{2}} + T_{i+1,j}^{k+\frac{1}{2}} = -T_{i,j-1}^{k} - T_{i,j+1}^{k} \tag{16}$$

$$T_{i,j-1}^{k+1} - 2(1+\beta^2)T_{i,j}^{k+1} + T_{i,j+1}^{k+1} = -T_{i-1,j}^{k+\frac{1}{2}} - T_{i+1,j}^{k+\frac{1}{2}} \tag{17}$$

where

$$\beta = \frac{\triangle x}{\triangle y}$$

$$\omega = RelaxationFactor$$

4 Results and Inferences

4.1 Problem 1: Transient Solution

- FTCS was used to solve the 2D Unsteady heat conduction equation
- ADI (Alternating Direction Implicit) Method was used to verify the solution obtained by FTCS Method.

Method	Number of Iterations	Time taken to reach Steady state
FTCS	3750	26.4698s
ADI	2056	39.3200s

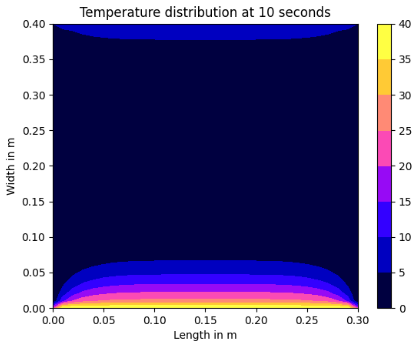
Table 1: Transient Solution : Method's Performance for $\triangle$t=0.1

Method	Number of Iterations	Time taken to reach Steady state
FTCS	3750	43.4708s
ADI	1119	21.6710s

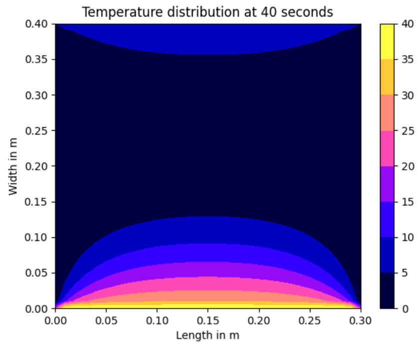
Table 2: Transient Solution : Method's Performance for $\triangle$t=0.2

- It is clear from the above table that ADI method has taken less time and less number of iterations to reach steady state as compared to FTCS.
- The solutions from FTCS matched with that of ADI method to a good extent.

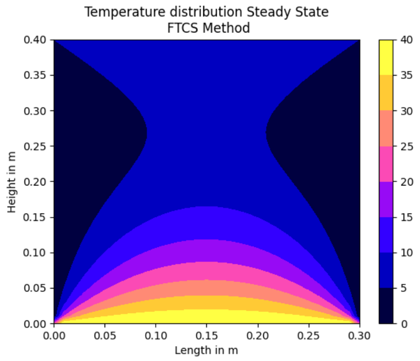
The following figures show the Temperature distributions at t=10s,t=40s and at Steady State.



(a) t=10 seconds

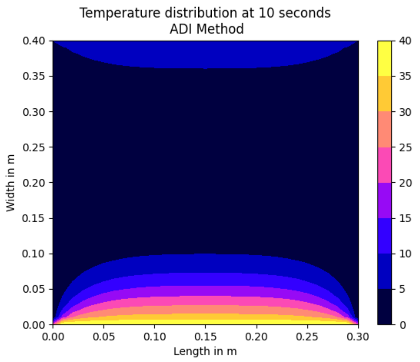


(b) t=40 seconds

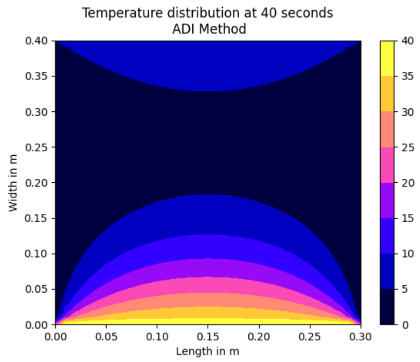


(c) Steady State

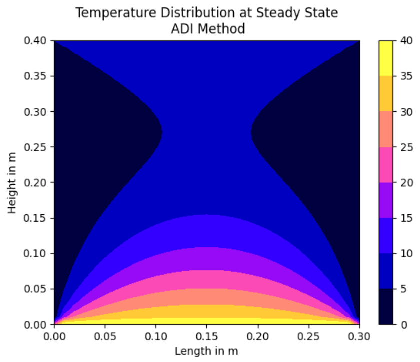
Figure 2: Temperature Distribution (FTCS Method)



(a) t=10 seconds



(b) t=40 seconds



(c) Steady State

Figure 3: Temperature Distribution (ADI Method)

4.2 Problem 2: Steady State Solution

The following methods are used to solve for Steady State solution of 2D Heat conduction equation in Cartesian cordinates

- Point Gauss Seidal Method
- Line Gauss Seidal Method
- PSOR (Point Successive Over Relaxation) Method
- LSOR (Line Successive Over Relaxation) Method

The computation time and iterations taken by each method to converge is tabulated below:

Method	Number of Iterations	Time taken to reach Steady state	Maximum Error
Point Gauss Seidal	1871	8.5990s	343.125
Line Gauss Seidal	572	7.1129s	715.19
PSOR	81	0.4756s	5689.07
LSOR	64	0.6454s	7221.4
ADI	550	8.4989s	823.86

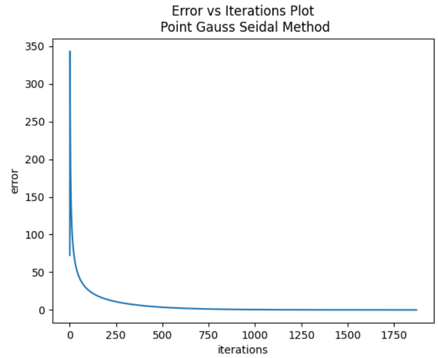
Table 3: Steady State Solution : Method's Performance

NOTE:

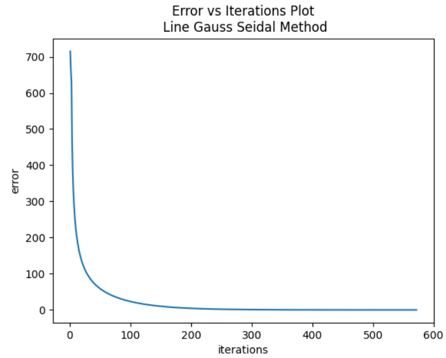
- *The Number of iterations and time taken can vary. These values are obtained without plotting the graphs for intermediate times*
- *The Steady state temperature distributions are plotted in the following section*

The following observations can be made from above tables:

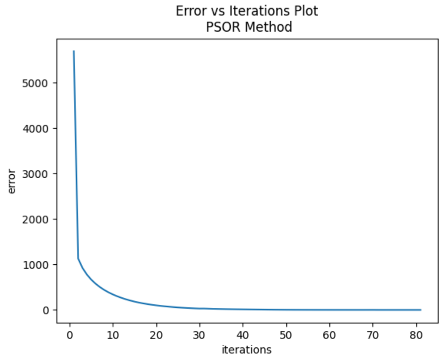
- Line Successive Over Relaxation Method has taken the least number of iterations.
- Point Successive Over Relaxation Method has taken least time to reach steady state, despite having more iterations than LSOR.
- LSOR Method has the maximum error value among all the other methods
- Successive Over Relaxation Methods have performed well in comparison with normal methods in terms of :
  - Number of iterations to reach Steady state
  - Computation time required to reach Steady State



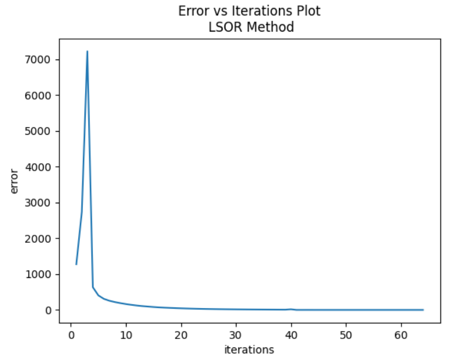
(a) Point Gauss Seidal Method



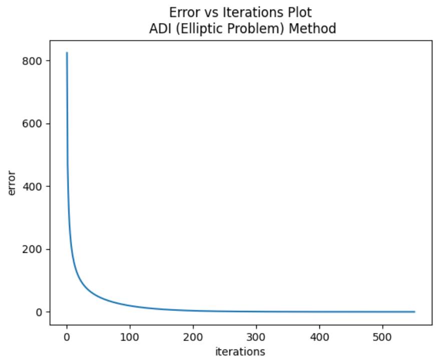
(b) Line Gauss Seidal Method



(c) PSOR Method



(d) LSOR Method



(e) ADI Method

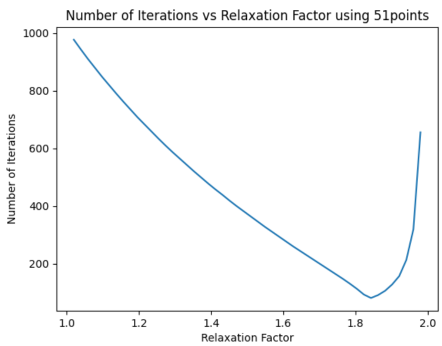
Figure 4: Error vs Iteration Plots

4.2.1 Calculating the Optimum relaxation factor

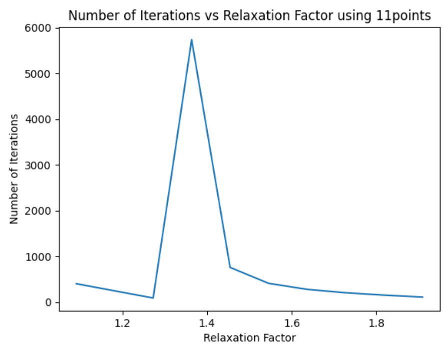
The relaxation factor for Successive Over Relaxation methods is in the range :

$$1 < \omega < 2$$

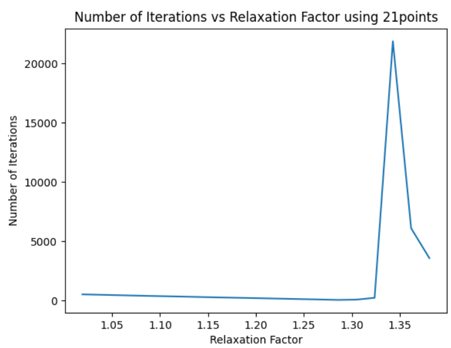
- PSOR Method :
  - The Number of iterations vs Relaxation factor graph is plotted and the Relaxation factor which yielded least number of iterations is selected as optimum relaxation factor.
  - From figure 4(a), it can be seen that the least number of iterations are obtained when the relaxation factor has a value of 1.8 approximately.
  - The approximate value for Optimum relaxation factor is : $\omega = 1.843137$



(a) PSOR Method



(b) LSOR Method



(c) LSOR Method (truncated range)

Figure 5: Iterations vs Relaxation Factor Plots

- LSOR Method:
  - It can be seen from the figure 4(b) that beyond $\omega = 1.2$, the number of iterations are rising.
  - From visual inspection, the minimum number of iterations are obtained in range of 1 to 1.3
  - In reference to figure 4(c), the optimum relaxation factor for LSOR method is calculated using 21 points in the truncated range.
  - The approximate value for optimum relaxation factor is : $\omega = 1.285714$

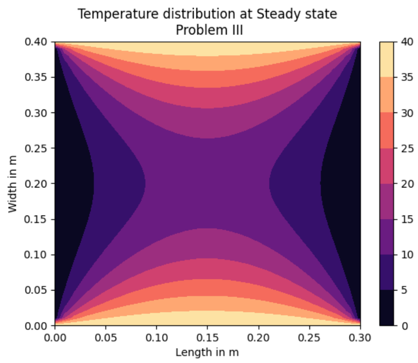
4.3 Problem 3: Modified Boundary Conditions

The changes made to the problem are :

- Case (a) The top wall (y=0.4 plane) temperature is changed to 40^0C
- Case (b) The domain of the problem is divided into a single quadrant and solved for steady state temperature distribution

4.3.1 Case (a) Solve for Steady State temperature distribution

The method used for solving for Steady State temperature distribution is *Point Successive Over Relaxation (PSOR)* with optimum relaxation value. The steady state temperature distribution is obtained as follows :



(a) Steady State temperature distribution (PSOR)

(b) Screenshot 1

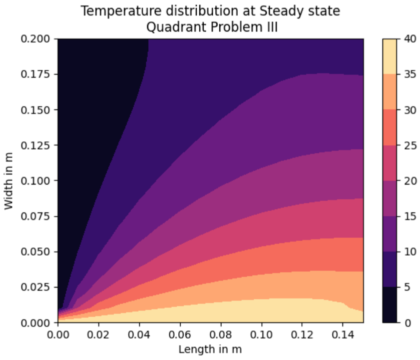
Figure 6: Steady State Temperature Distribution
Complete Domain

Domain	Number of Iterations	Time taken to reach Steady state
Complete	89	0.79135s

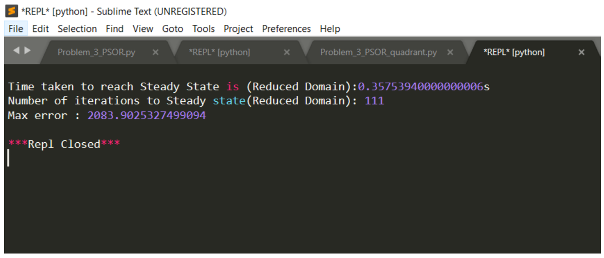
Table 4: PSOR Method's Performance for Complete domain

4.3.2 Case (b) Steady State Solution for Reduced Domain Problem

In this problem, the domain is divided into four quadrants, with two dirichlet boundary conditions and two neumann boundary conditions on four sides of the quadrant.



(a) Single Quadrant



(b) Screenshot 2

Figure 7: Steady State Temperature Distribution
Reduced Domain

Domain	Number of Iterations	Time taken to reach Steady state
Single Quadrant	111	0.35753s

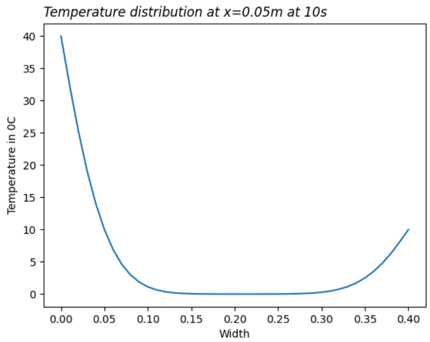
Table 5: PSOR Method's Performance for Reduced Computational domain

It can be seen that the reduced domain is computationally less costly even though the number of iterations are more than complete domain.

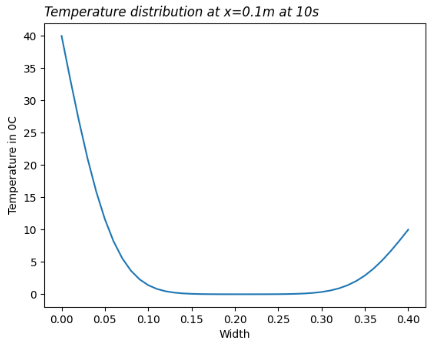
5 Temperature Distribution Plots:

5.1 Problem 1: Transient Temperature Distributions

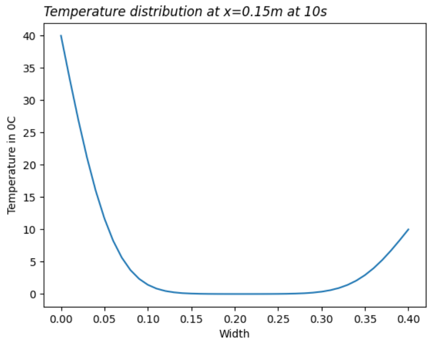
5.1.1 FTCS Method



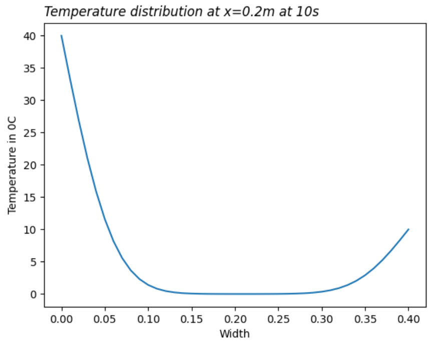
(a) x= $0.05m$



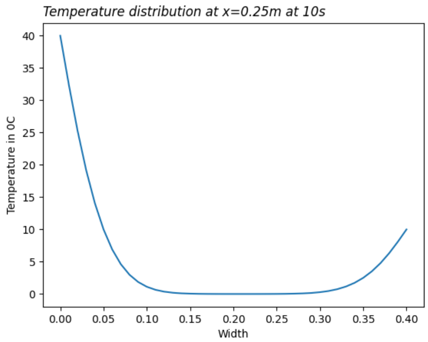
(b) x= $0.1m$



(c) x= $0.15m$

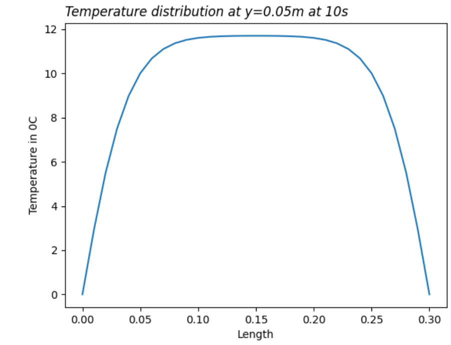


(d) x= $0.2m$

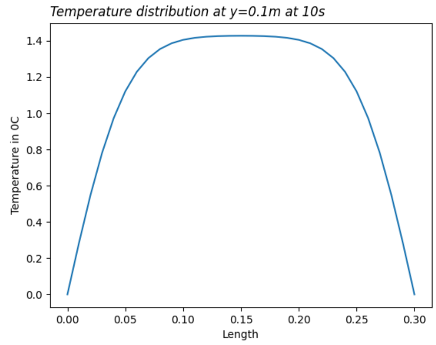


(e) x= $0.25m$

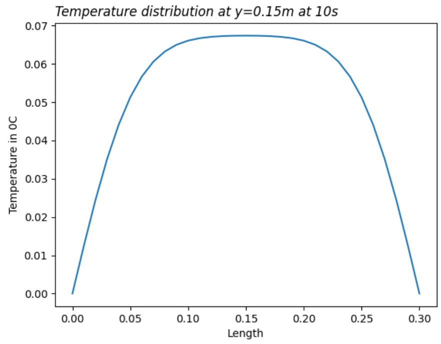
Figure 8: FTCS: Temperature vs Width(y) at 10s
Time step : $\triangle$t=0.1



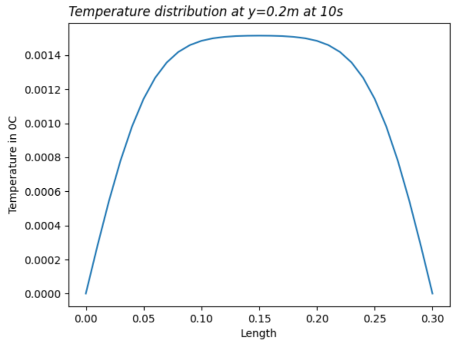
(a) y= $0.05m$



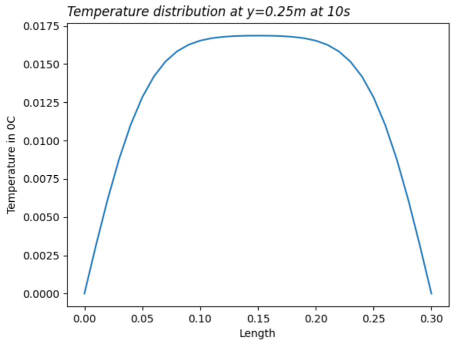
(b) y= $0.1m$



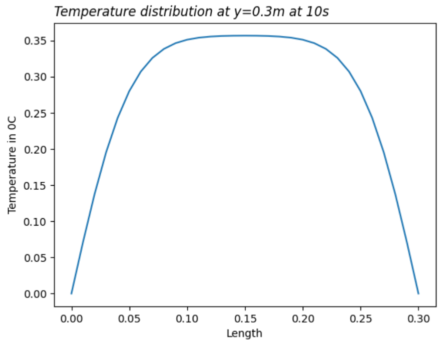
(c) y= $0.15m$



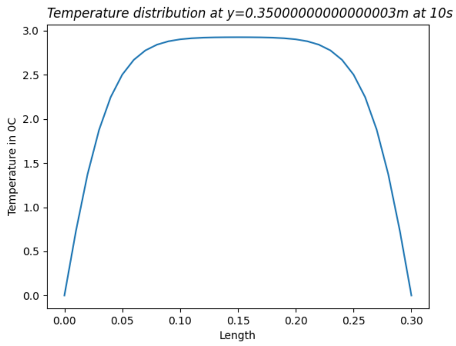
(d) y= $0.2m$



(e) y= $0.25m$

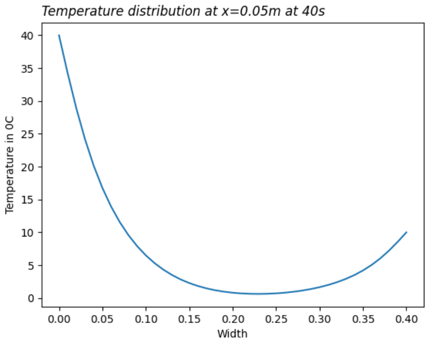


(f) y= $0.3m$

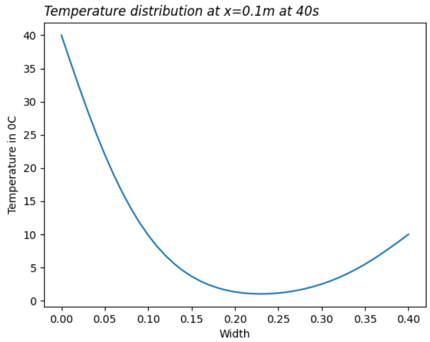


(g) y= $0.35m$

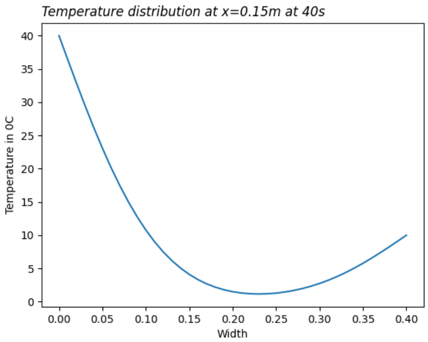
Figure 9: FTCS: Temperature vs Length(x) at 10s
Time step : $\triangle$t=0.1



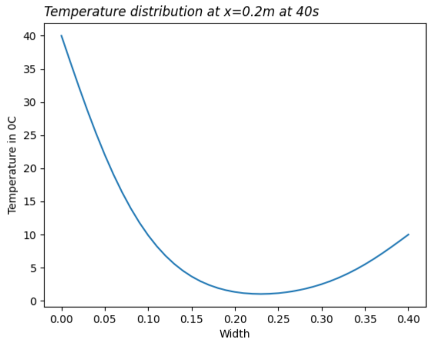
(a) x$= 0.05m$



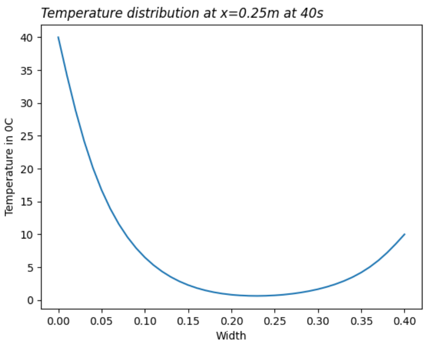
(b) x$= 0.1m$



(c) x$= 0.15m$

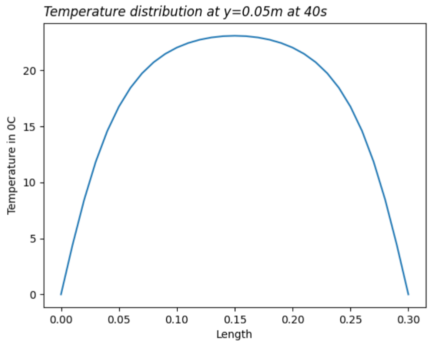


(d) x$= 0.2m$

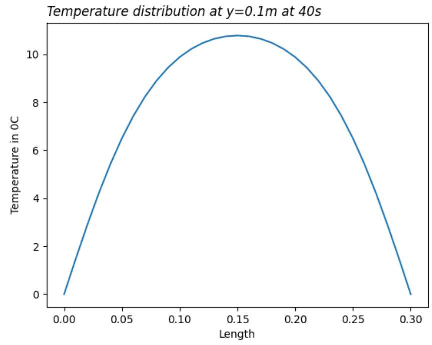


(e) x$= 0.25m$

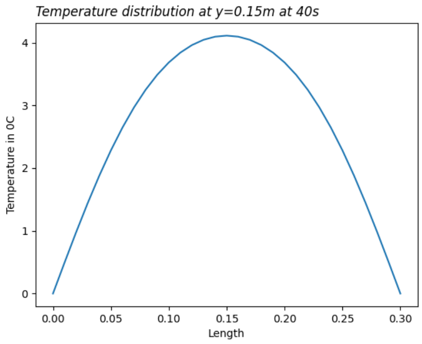
Figure 10: FTCS: Temperature vs Width(y) at 40s
Time step : $\triangle$t=0.1



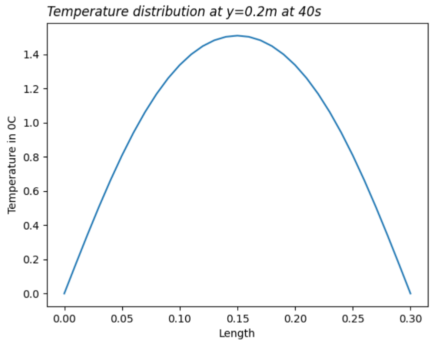
(a) y= $0.05m$



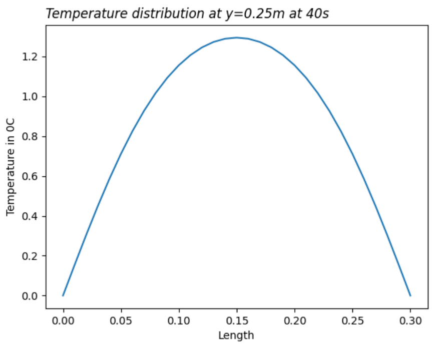
(b) y= $0.1m$



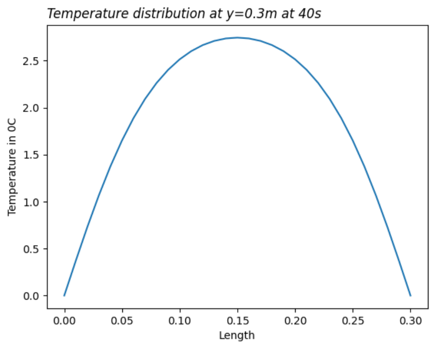
(c) y= $0.15m$



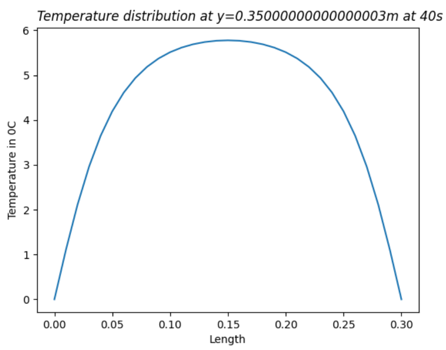
(d) y= $0.2m$



(e) y= $0.25m$

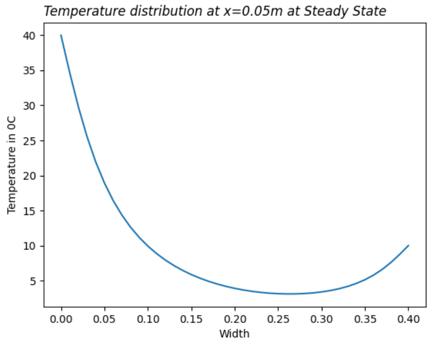


(f) y= $0.3m$

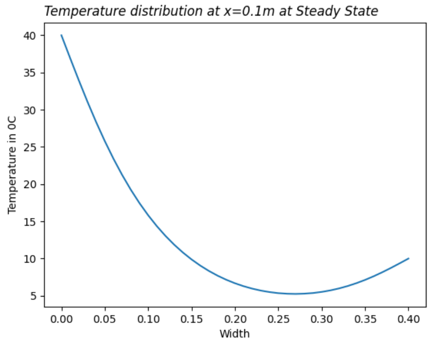


(g) y= $0.35m$

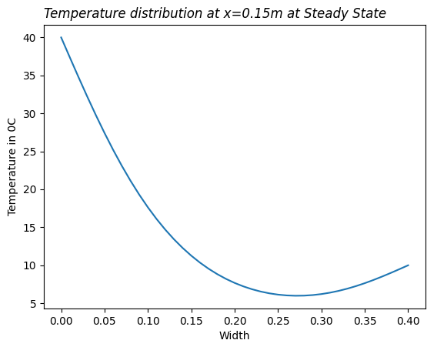
Figure 11: FTCS: Temperature vs Length(x) at 40s
Time step : $\triangle$t=0.1



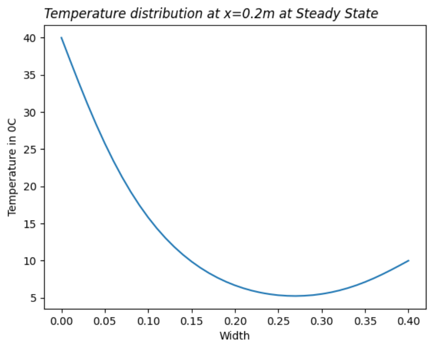
(a) x= $0.05m$



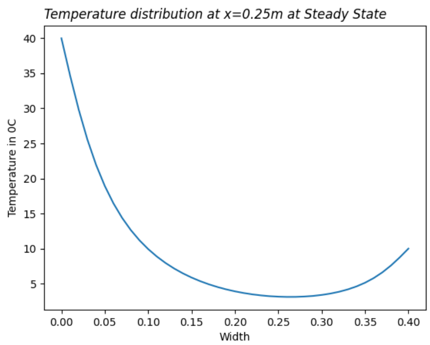
(b) x= $0.1m$



(c) x= $0.15m$

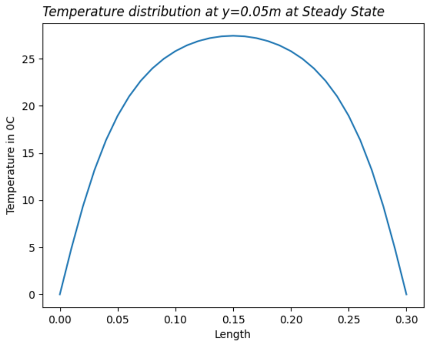


(d) x= $0.2m$

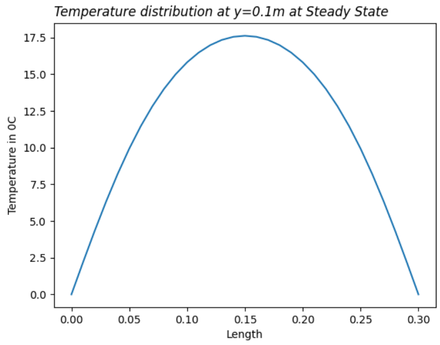


(e) x= $0.25m$

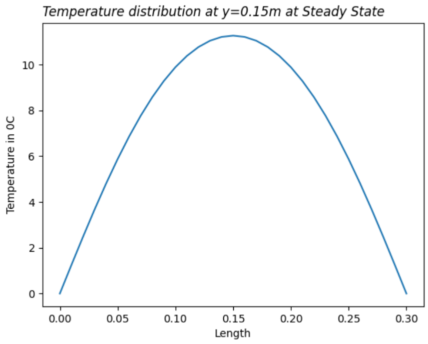
Figure 12: FTCS: Temperature vs Width(y) at Steady State
Time step : $\triangle$t=0.1



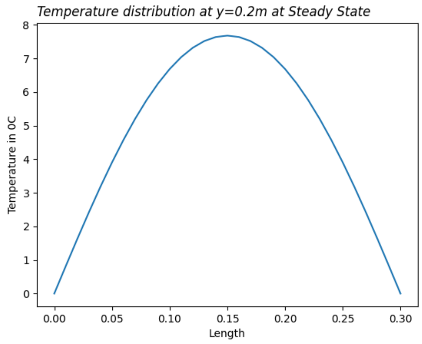
(a) y= $0.05m$



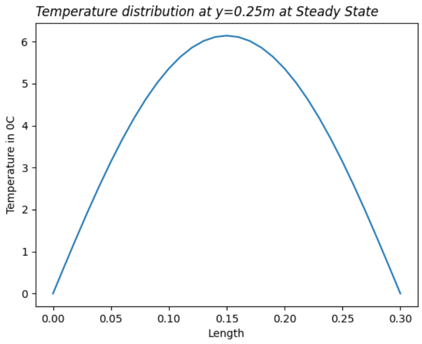
(b) y= $0.1m$



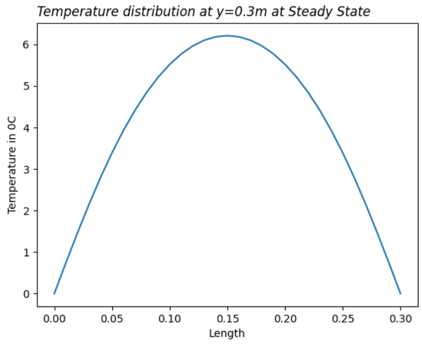
(c) y= $0.15m$



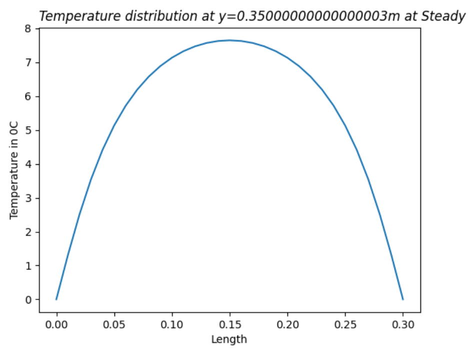
(d) y= $0.2m$



(e) y= $0.25m$

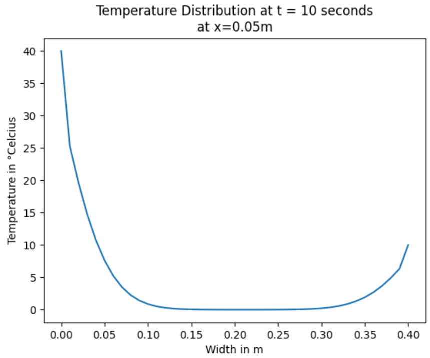


(f) y= $0.3m$

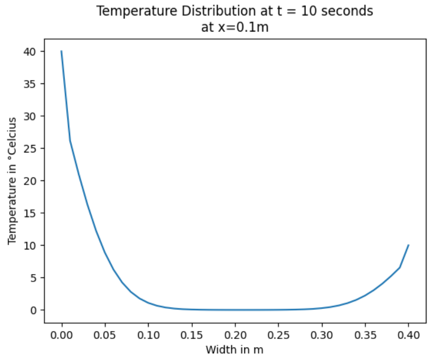


(g) y= $0.35m$

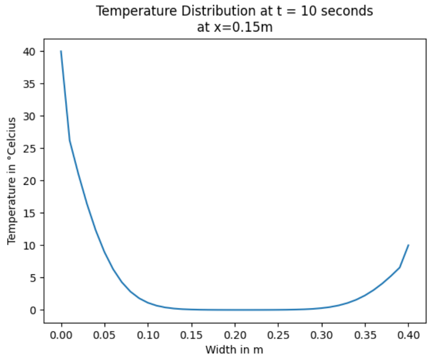
Figure 13: FTCS: Temperature vs Length(x) at Steady State
Time step : $\triangle$t=0.1



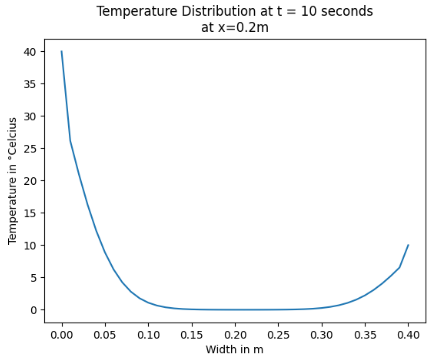
(a) x$= 0.05m$



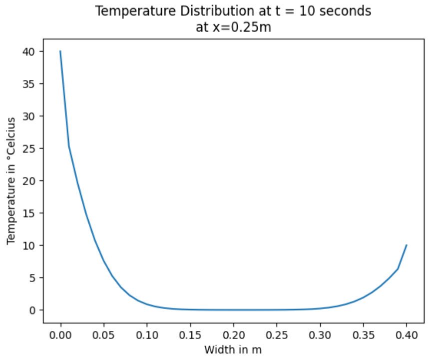
(b) x$= 0.1m$



(c) x$= 0.15m$

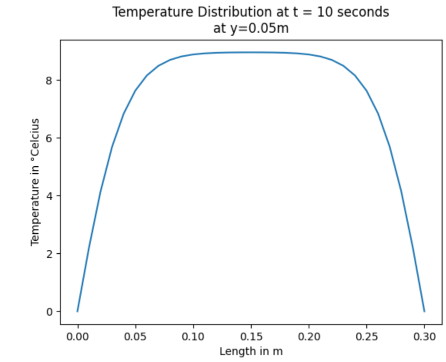


(d) x$= 0.2m$

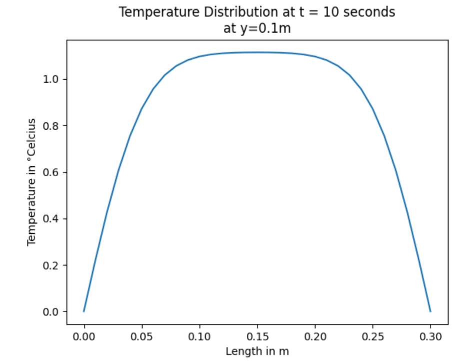


(e) x$= 0.25m$

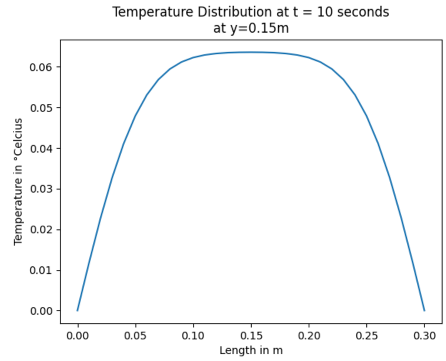
Figure 14: FTCS: Temperature vs Width(y) at 10s
Time step : $\triangle$t=0.2



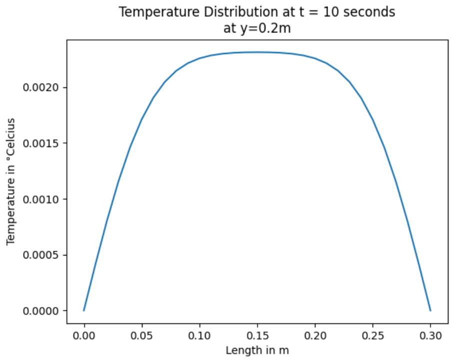
(a) y= $0.05m$



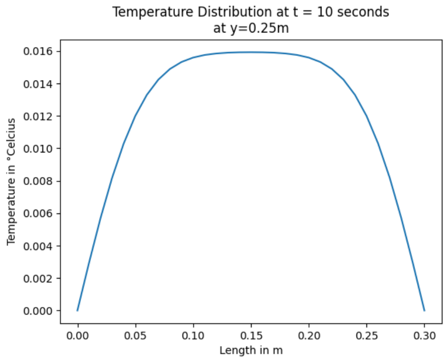
(b) y= $0.1m$



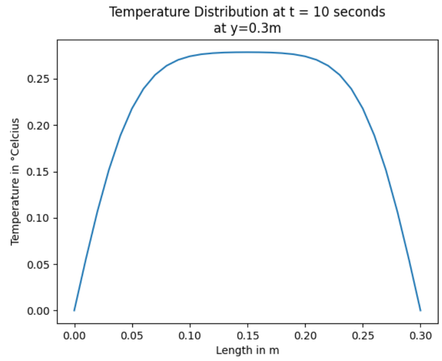
(c) y= $0.15m$



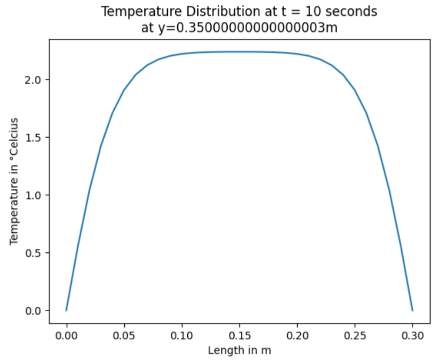
(d) y= $0.2m$



(e) y= $0.25m$

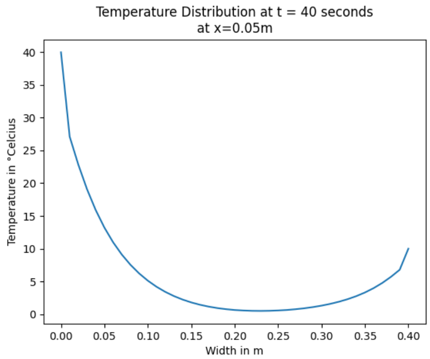


(f) y= $0.3m$

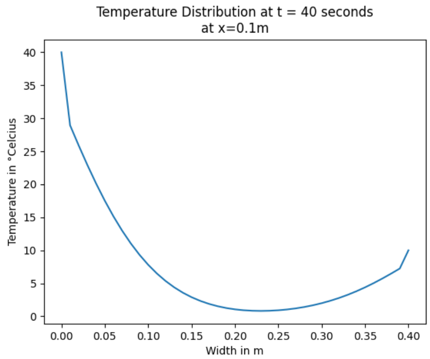


(g) y= $0.35m$

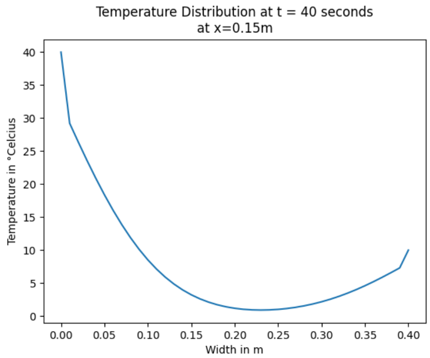
Figure 15: FTCS: Temperature vs Length(x) at 10s
Time step : $\triangle$t=0.2



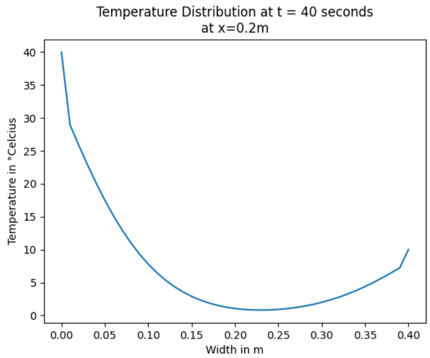
(a) x= $0.05m$



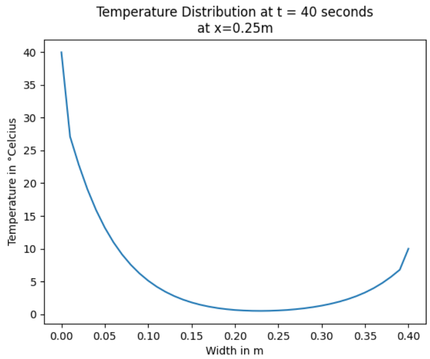
(b) x= $0.1m$



(c) x= $0.15m$

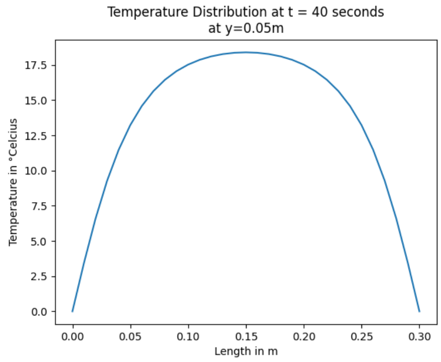


(d) x= $0.2m$

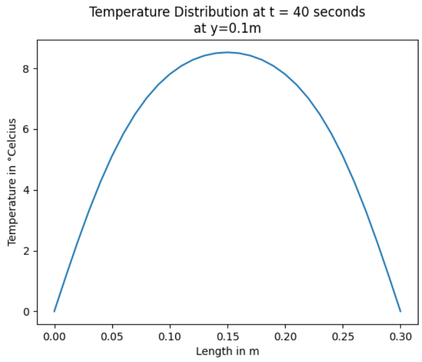


(e) x= $0.25m$

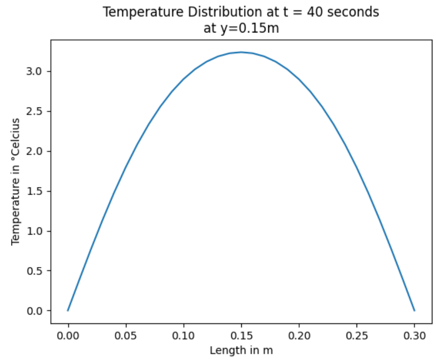
Figure 16: FTCS: Temperature vs Width(y) at 40s
Time step : $\triangle$t=0.2



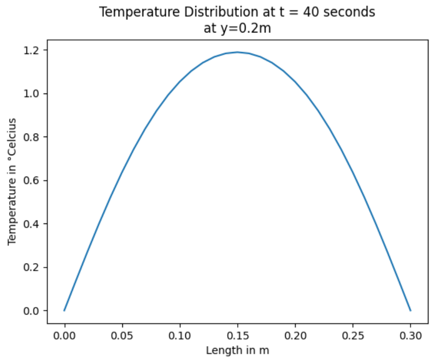
(a) y= $0.05m$



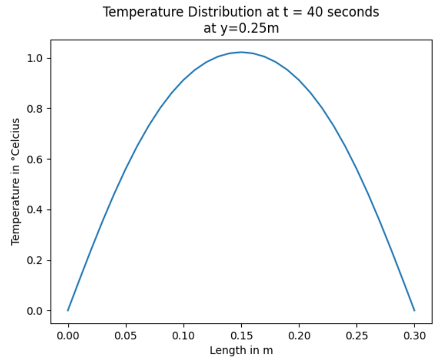
(b) y= $0.1m$



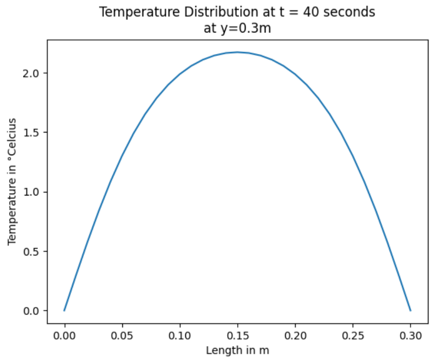
(c) y= $0.15m$



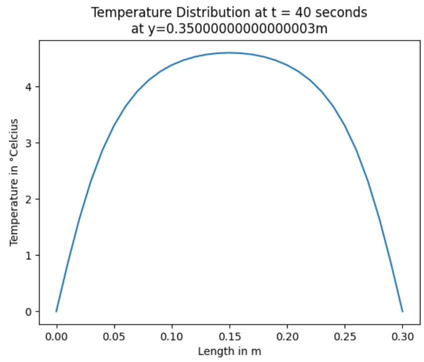
(d) y= $0.2m$



(e) y= $0.25m$

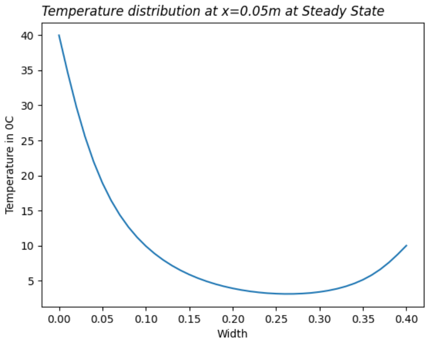


(f) y= $0.3m$

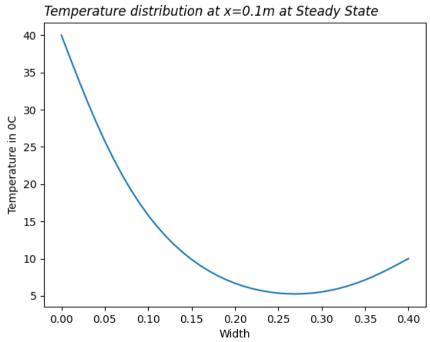


(g) y= $0.35m$

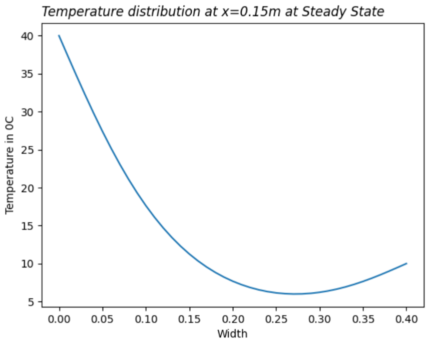
Figure 17: FTCS: Temperature vs Length(x) at 40s
Time step : $\triangle$t=0.2



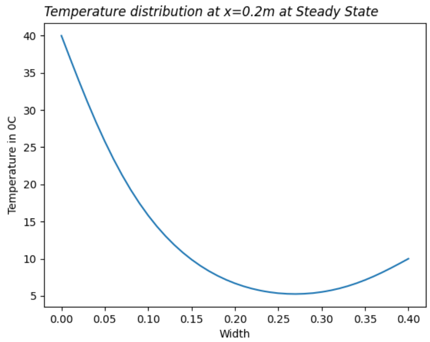
(a) x= $0.05m$



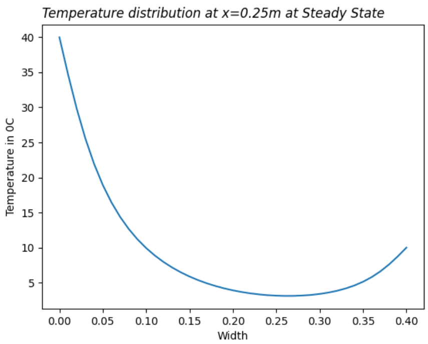
(b) x= $0.1m$



(c) x= $0.15m$

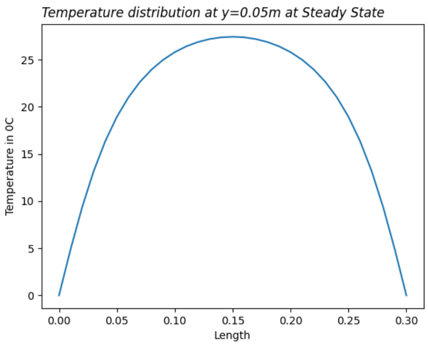


(d) x= $0.2m$

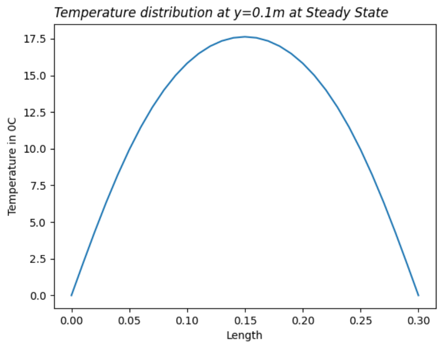


(e) x= $0.25m$

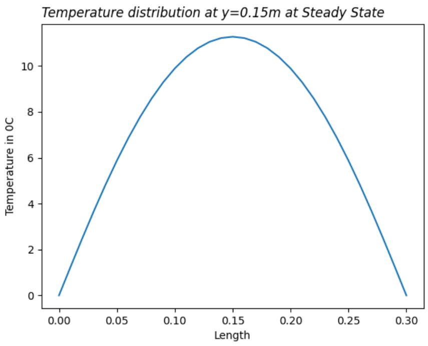
Figure 18: FTCS: Temperature vs Width(y) at Steady State
Time step : $\triangle$t=0.2



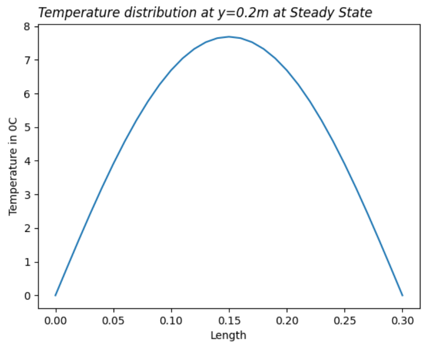
(a) y= $0.05m$



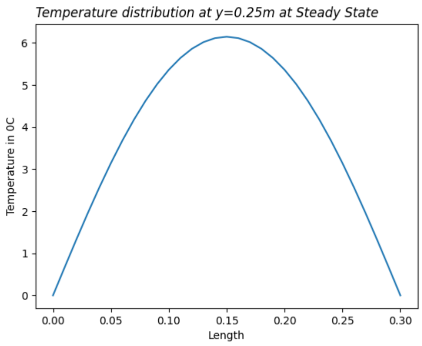
(b) y= $0.1m$



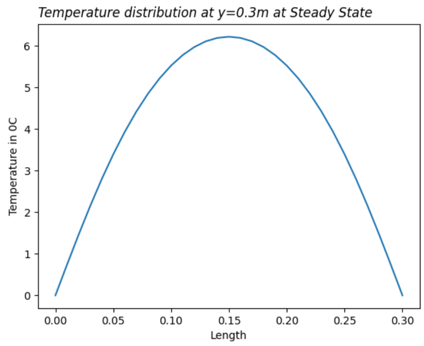
(c) y= $0.15m$



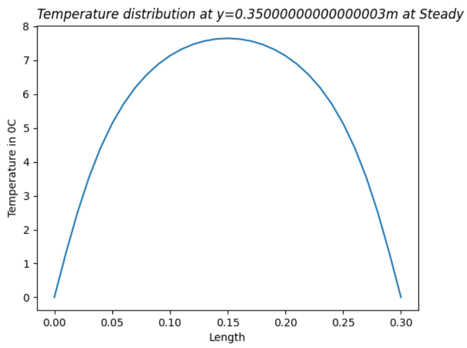
(d) y= $0.2m$



(e) y= $0.25m$



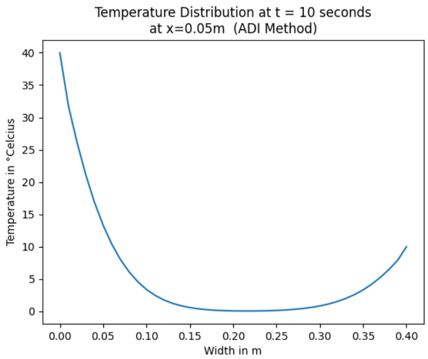
(f) y= $0.3m$



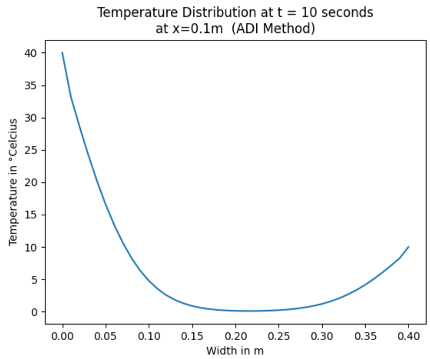
(g) y= $0.35m$

Figure 19: FTCS: Temperature vs Length(x) at Steady State
Time step : $\triangle$t=0.2

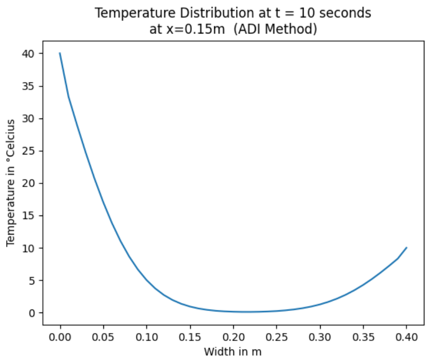
5.1.2 ADI Method



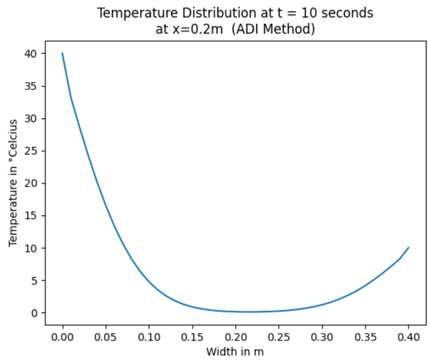
(a) x= $0.05m$



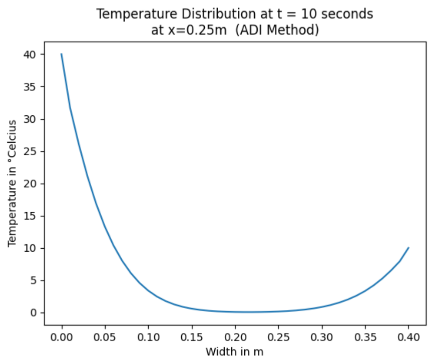
(b) x= $0.1m$



(c) x= $0.15m$

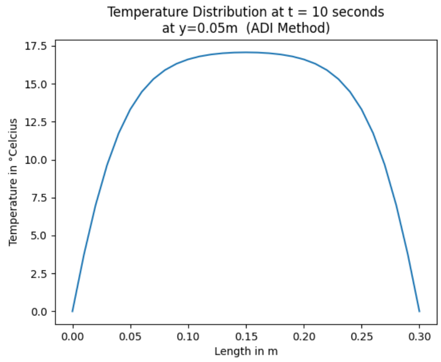


(d) x= $0.2m$

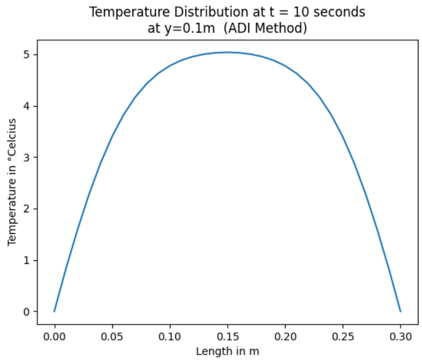


(e) x= $0.25m$

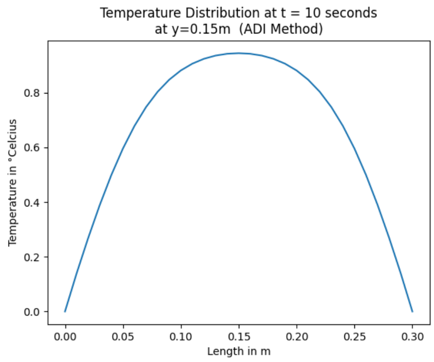
Figure 20: ADI: Temperature vs Width(y) at 10s
Time step : $\triangle$t=0.1



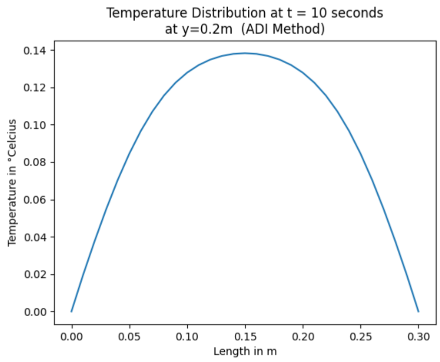
(a) y= $0.05m$



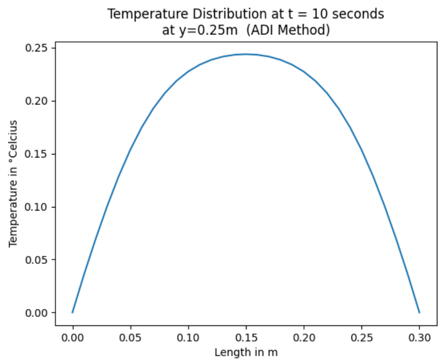
(b) y= $0.1m$



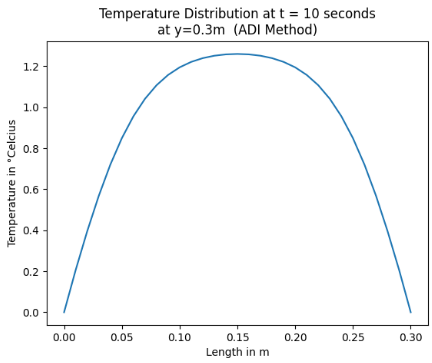
(c) y= $0.15m$



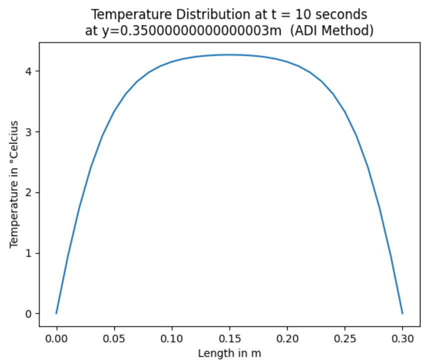
(d) y= $0.2m$



(e) y= $0.25m$

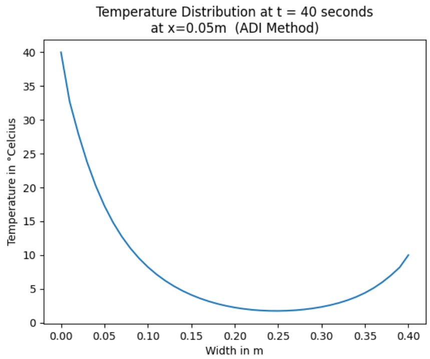


(f) y= $0.3m$

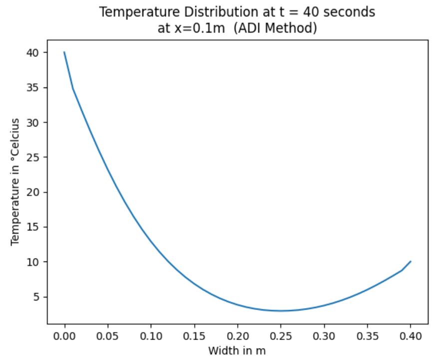


(g) y= $0.35m$

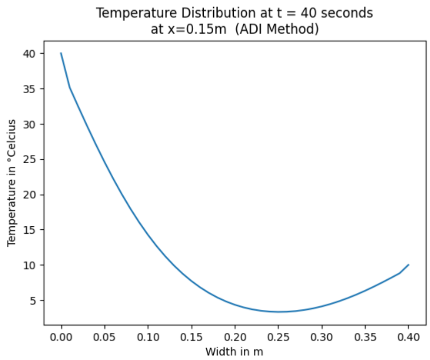
Figure 21: ADI: Temperature vs Length(x) at 10s
Time step : △t=0.1



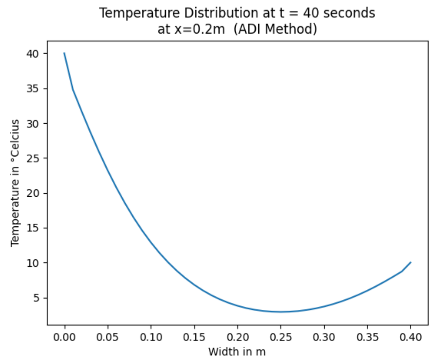
(a) x= $0.05m$



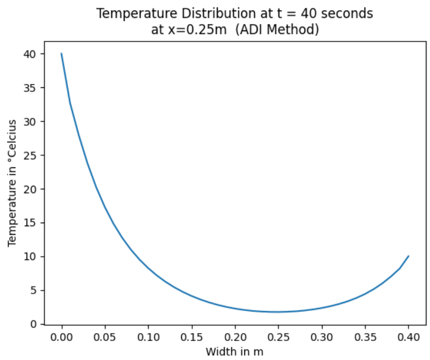
(b) x= $0.1m$



(c) x= $0.15m$

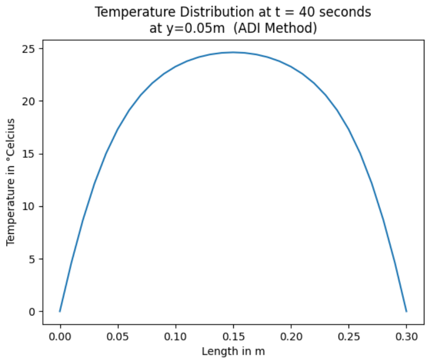


(d) x= $0.2m$

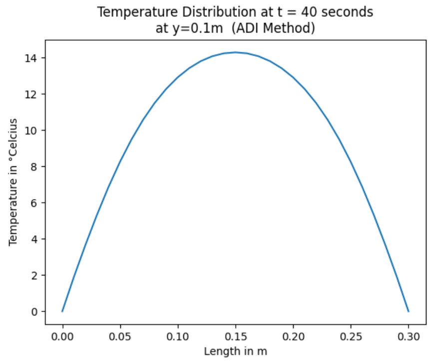


(e) x= $0.25m$

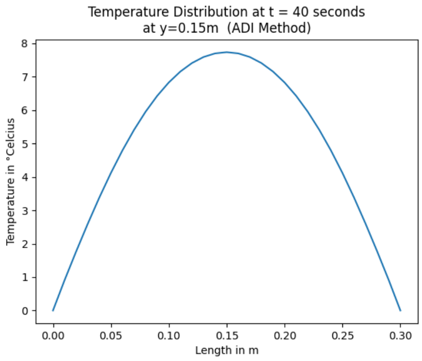
Figure 22: ADI: Temperature vs Width(y) at 40s
Time step : $\triangle$t=0.1



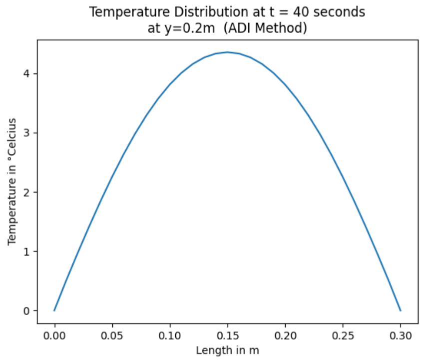
(a) y= $0.05m$



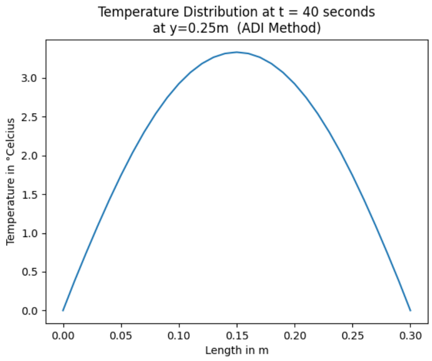
(b) y= $0.1m$



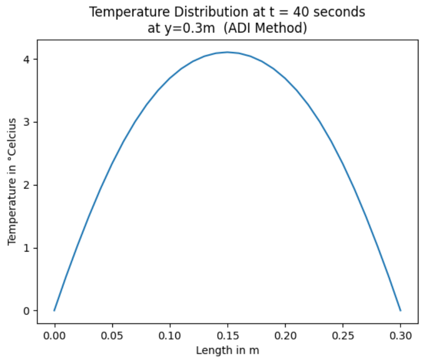
(c) y= $0.15m$



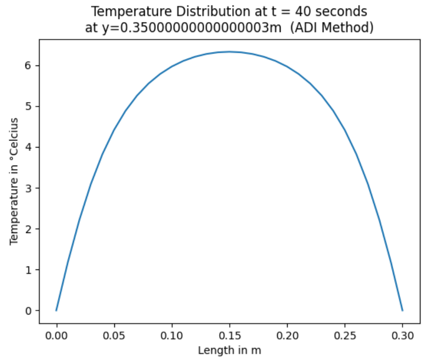
(d) y= $0.2m$



(e) y= $0.25m$

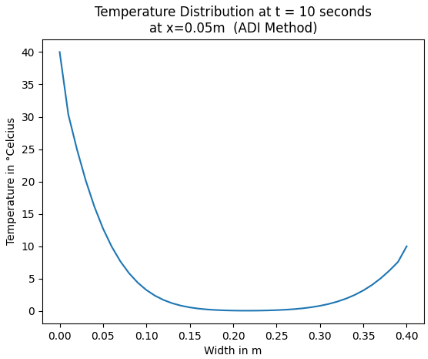


(f) y= $0.3m$

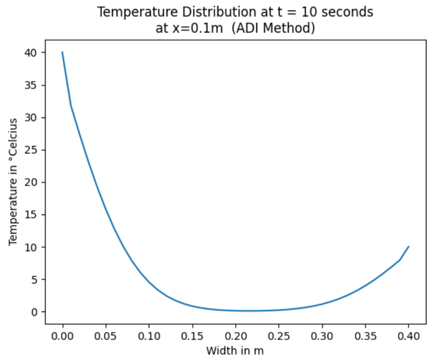


(g) y= $0.35m$

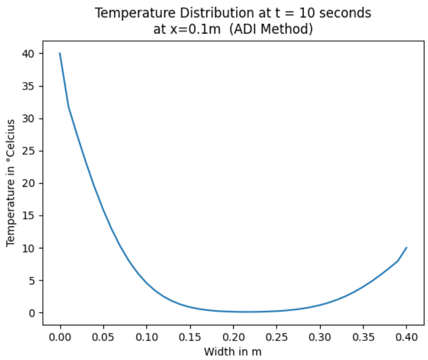
Figure 23: ADI: Temperature vs Length(x) at 40s
Time step : $\triangle$t=0.1



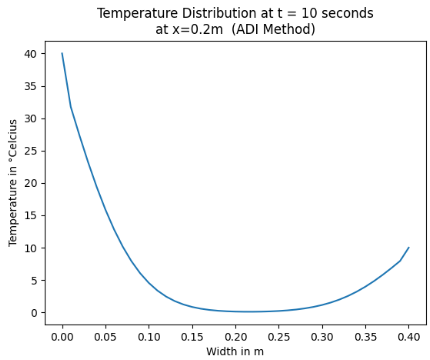
(a) x= $0.05m$



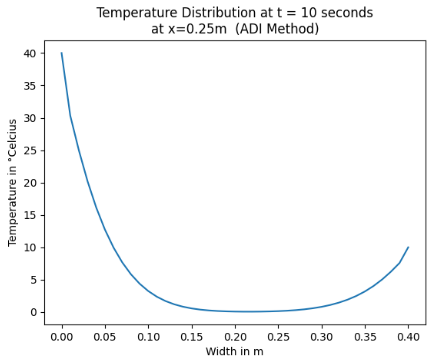
(b) x= $0.1m$



(c) x= $0.15m$

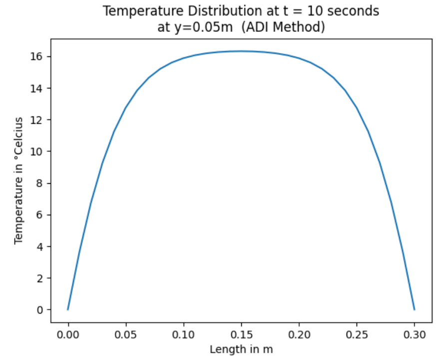


(d) x= $0.2m$

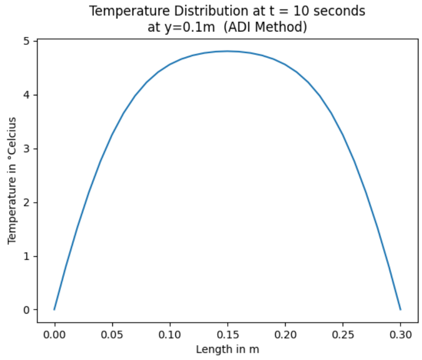


(e) x= $0.25m$

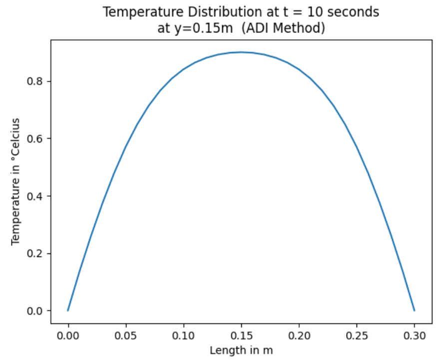
Figure 24: ADI: Temperature vs Width(y) at 10s
Time step : $\triangle$t=0.2



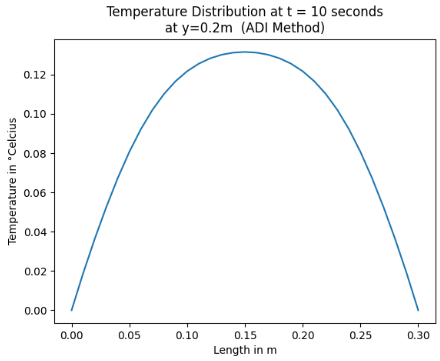
(a) y= $0.05m$



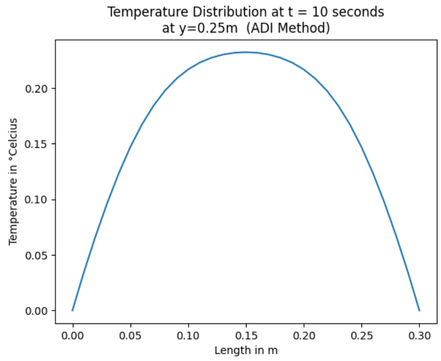
(b) y= $0.1m$



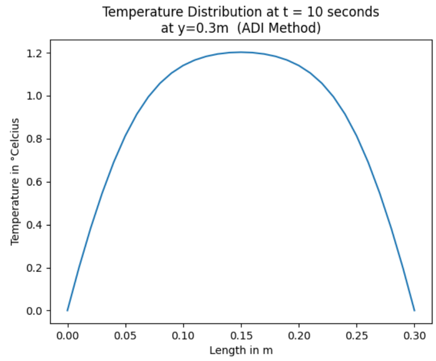
(c) y= $0.15m$



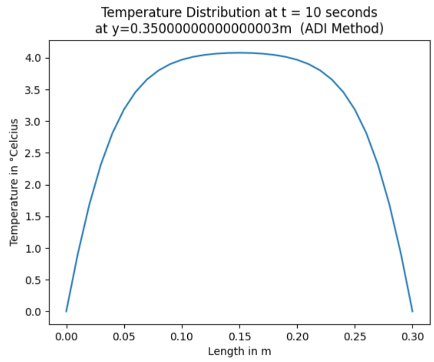
(d) y= $0.2m$



(e) y= $0.25m$

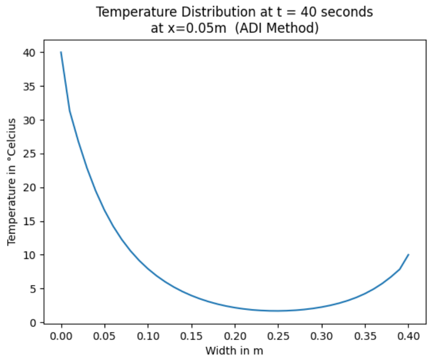


(f) y= $0.3m$

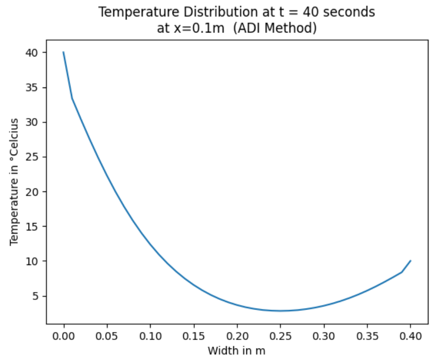


(g) y= $0.35m$

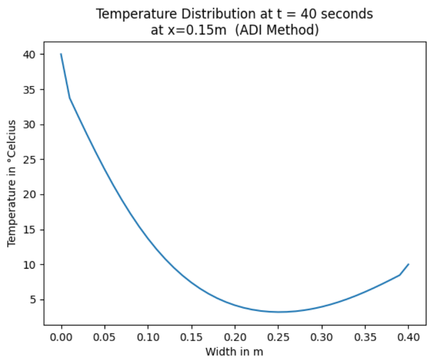
Figure 25: ADI: Temperature vs Length(x) at 10s
Time step : △t=0.2



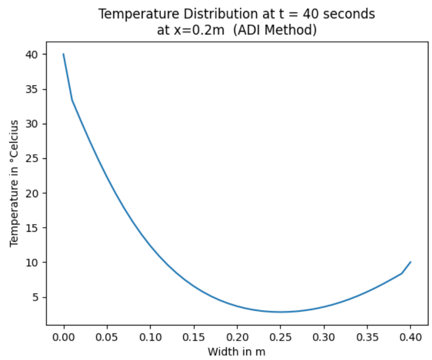
(a) x= $0.05m$



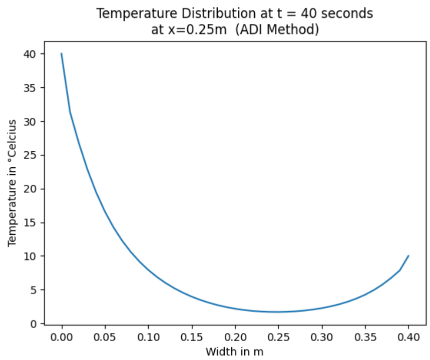
(b) x= $0.1m$



(c) x= $0.15m$

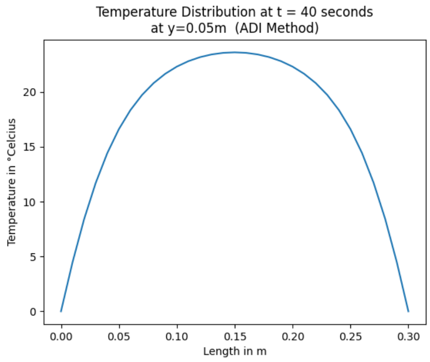


(d) x= $0.2m$

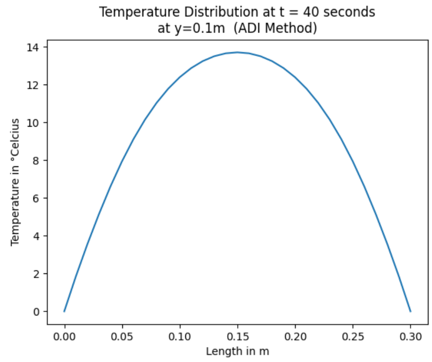


(e) x= $0.25m$

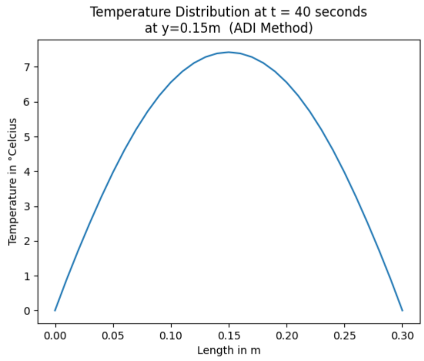
Figure 26: ADI: Temperature vs Width(y) at 40s
Time step : $\triangle$t=0.2



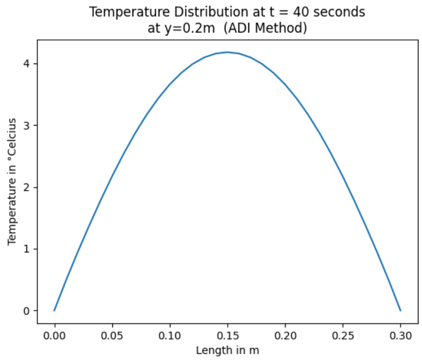
(a) y= $0.05m$



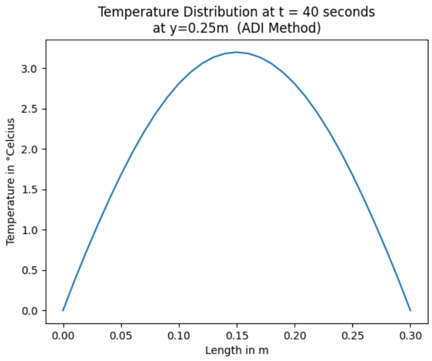
(b) y= $0.1m$



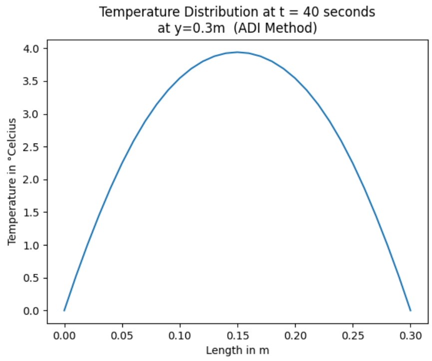
(c) y= $0.15m$



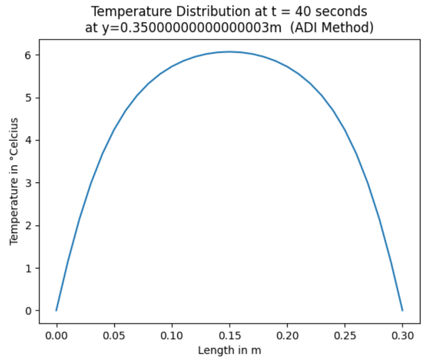
(d) y= $0.2m$



(e) y= $0.25m$

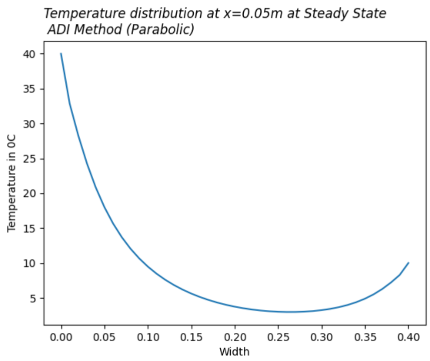


(f) y= $0.3m$

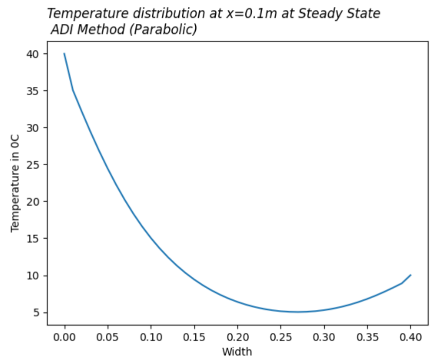


(g) y= $0.35m$

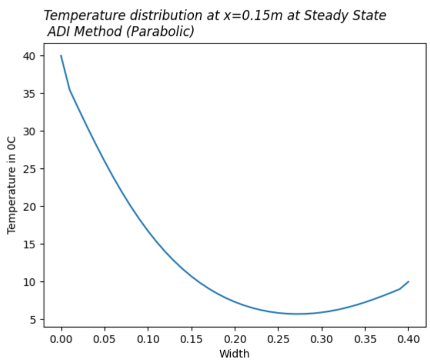
Figure 27: ADI: Temperature vs Length(x) at 40s
Time step : $\triangle$t=0.2



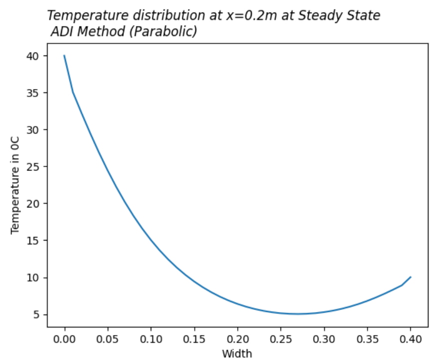
(a) x= $0.05m$



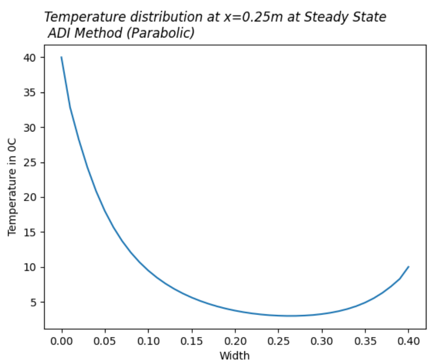
(b) x= $0.1m$



(c) x= $0.15m$

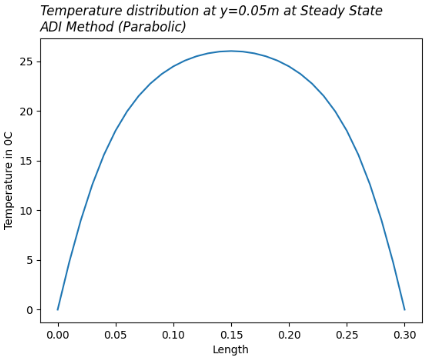


(d) x= $0.2m$

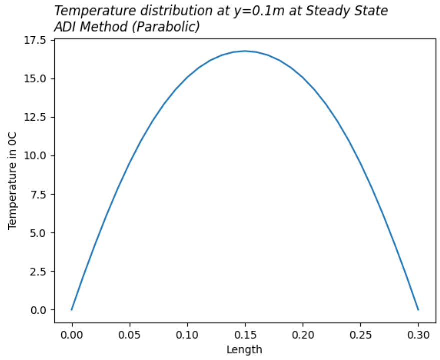


(e) x= $0.25m$

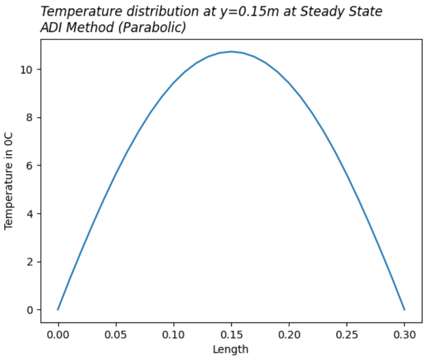
Figure 28: ADI: Temperature vs Width(y) at Steady State



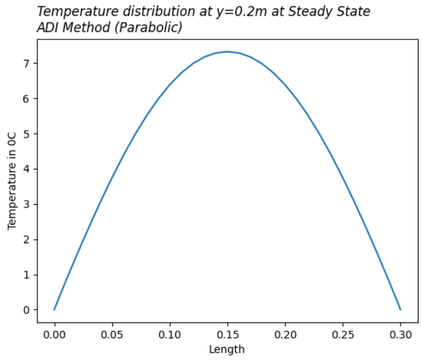
(a) y= $0.05m$



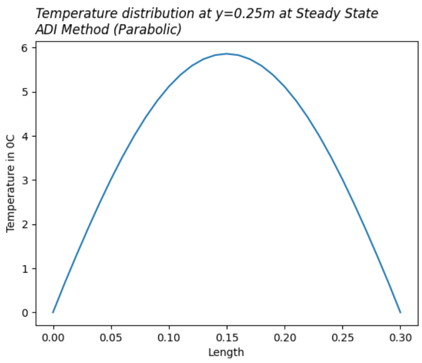
(b) y= $0.1m$



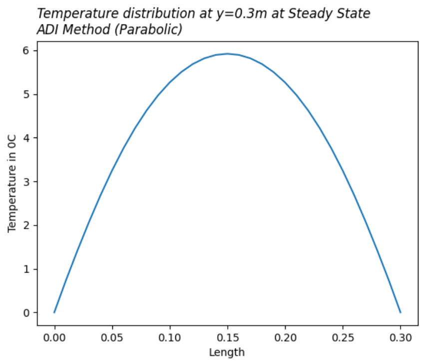
(c) y= $0.15m$



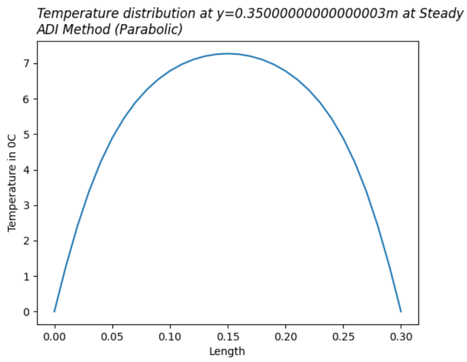
(d) y= $0.2m$



(e) y= $0.25m$



(f) y= $0.3m$



(g) y= $0.35m$

Figure 29: ADI: Temperature vs Length(x) at Steady State

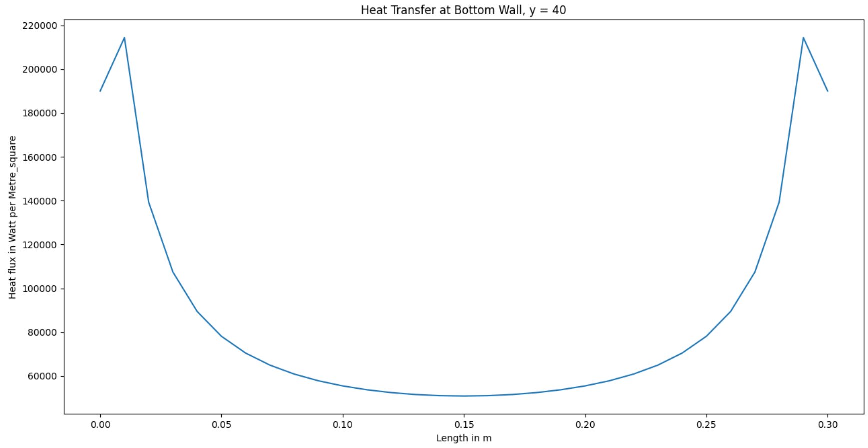


Figure 30: Top Wall Heat Flux

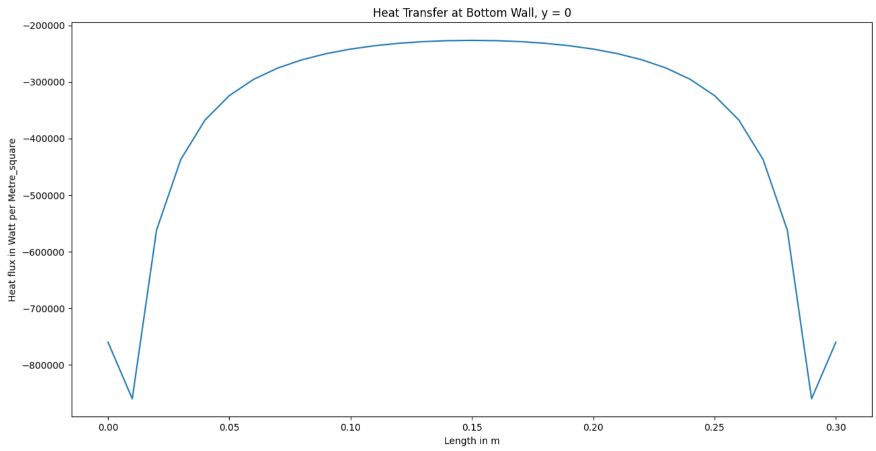
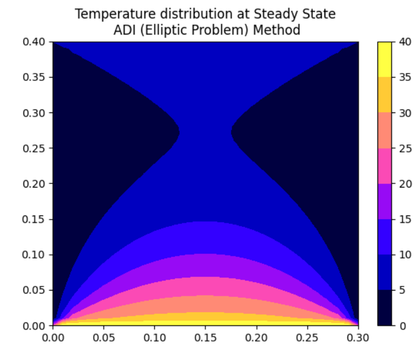


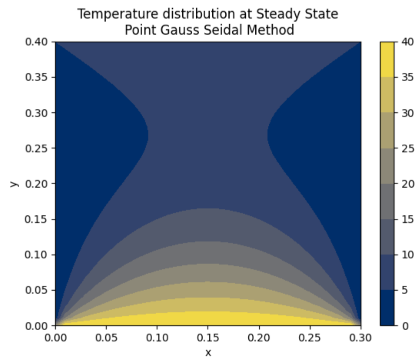
Figure 31: Bottom Wall Heat Flux

5.2 Problem 2: Steady State Temperature distributions

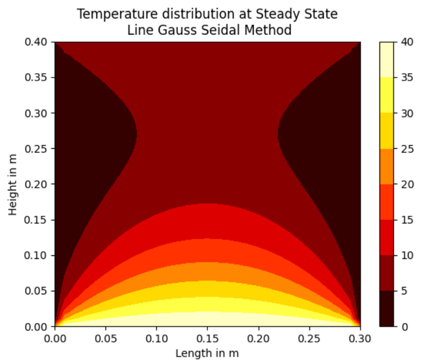
5.2.1 Contour PLots:



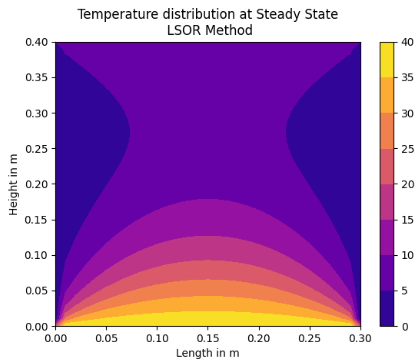
(a) ADI Method



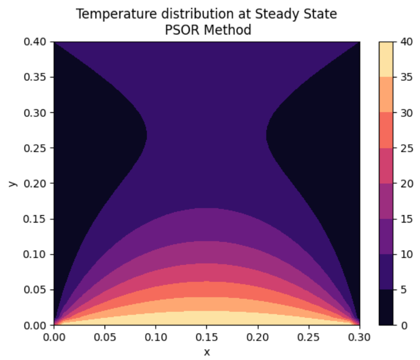
(b) Point Gauss Seidal Method



(c) Line Gauss Seidal Method



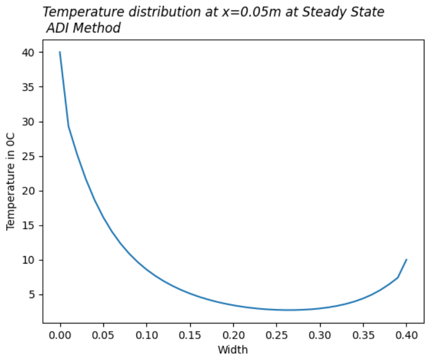
(d) LSOR Method



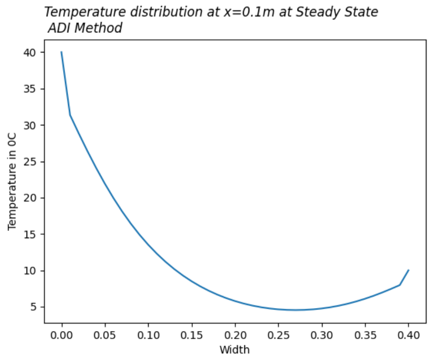
(e) PSOR Method

Figure 32: Steady State Temperature Distribution for Elliptic Problem

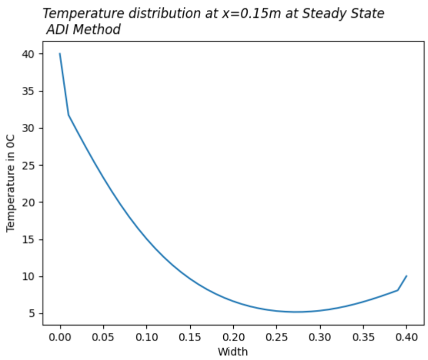
5.2.2 Temperature Distribution Plots:



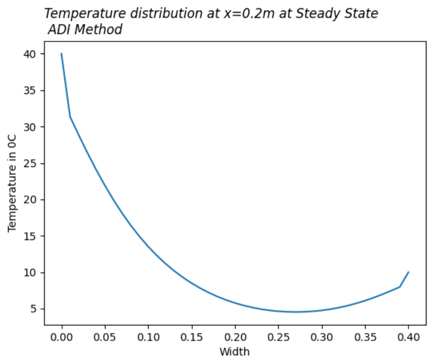
(a) x$= 0.05m$



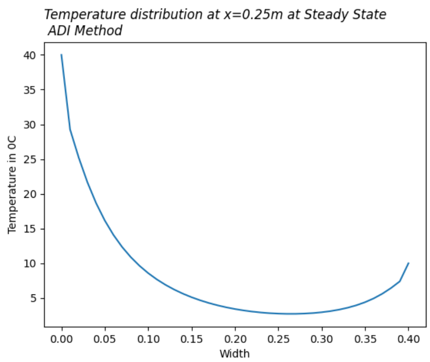
(b) x$= 0.1m$



(c) x$= 0.15m$

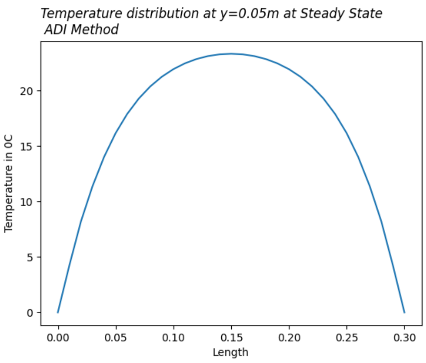


(d) x$= 0.2m$

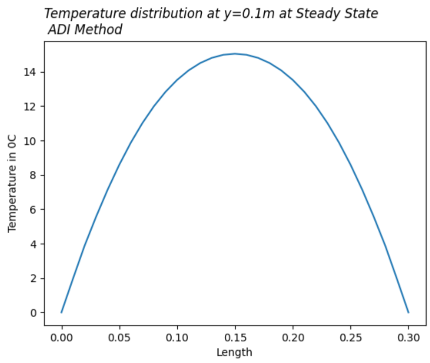


(e) x$= 0.25m$

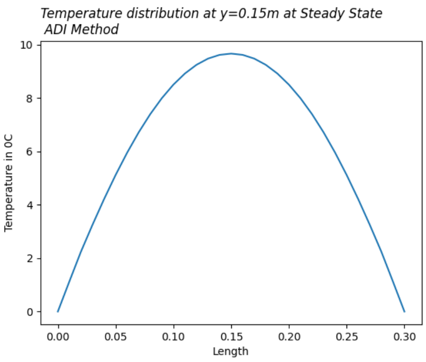
Figure 33: ADI: Temperature vs Width(y) at Steady State



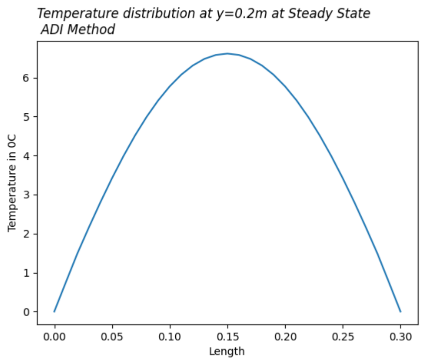
(a) y= $0.05m$



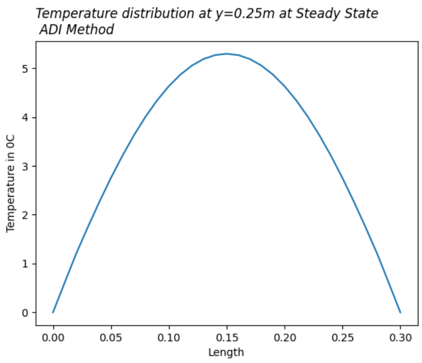
(b) y= $0.1m$



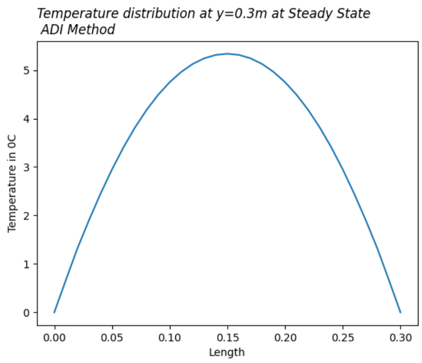
(c) y= $0.15m$



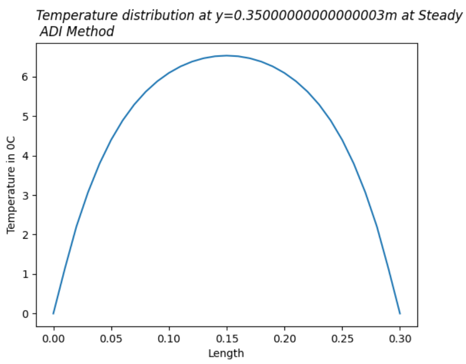
(d) y= $0.2m$



(e) y= $0.25m$

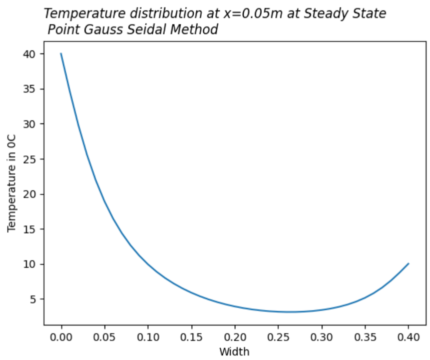


(f) y= $0.3m$

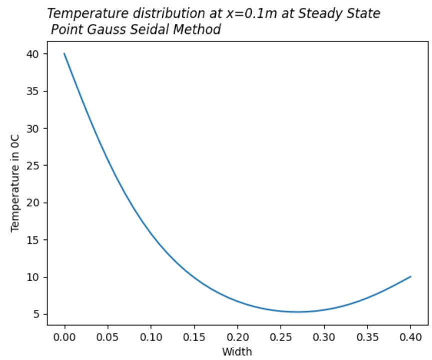


(g) y= $0.35m$

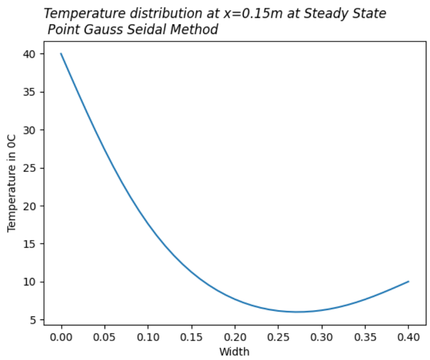
Figure 34: ADI: Temperature vs Length(x) at Steady State



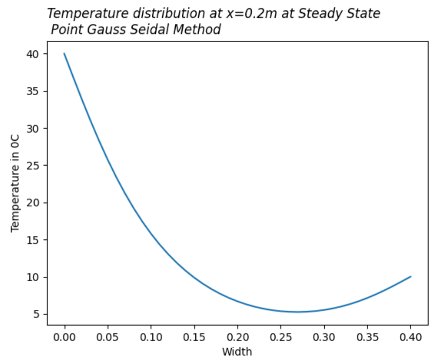
(a) x= $0.05m$



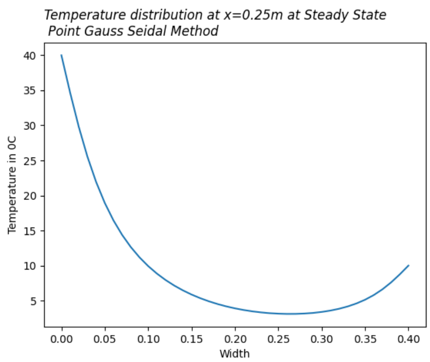
(b) x= $0.1m$



(c) x= $0.15m$

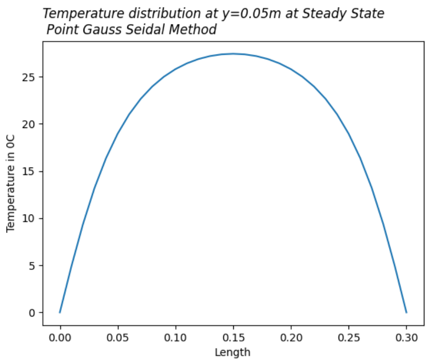


(d) x= $0.2m$

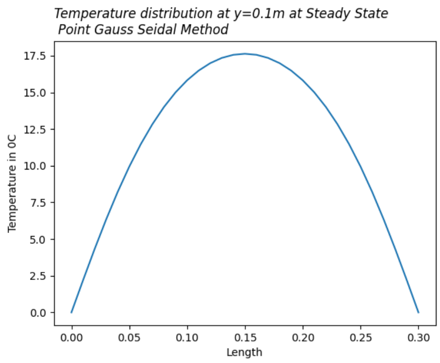


(e) x= $0.25m$

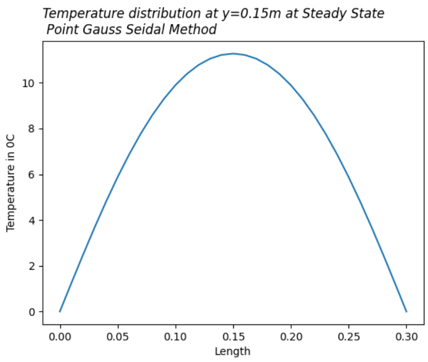
Figure 35: Point Gauss Seidal Method: Temperature vs Width(y) at Steady State



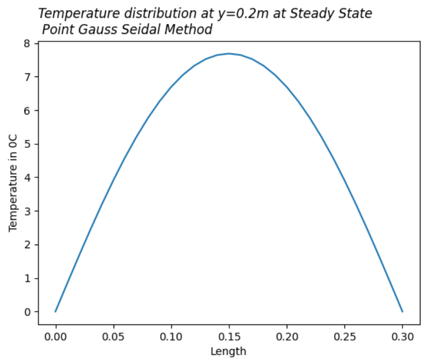
(a) y= $0.05m$



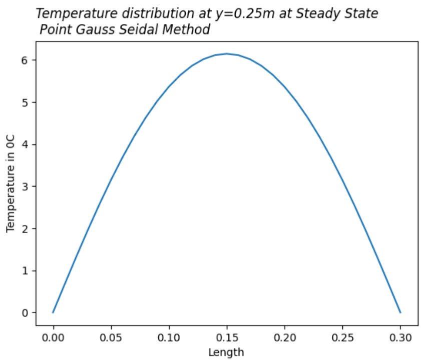
(b) y= $0.1m$



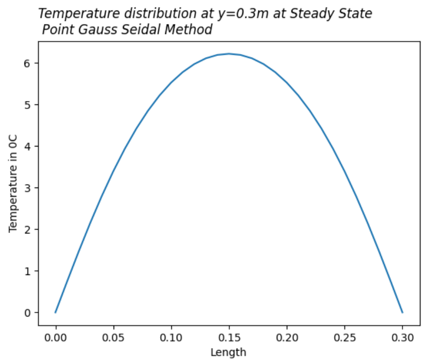
(c) y= $0.15m$



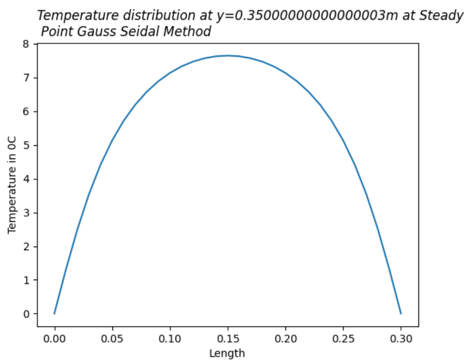
(d) y= $0.2m$



(e) y= $0.25m$

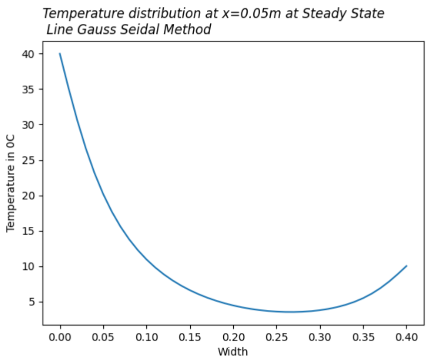


(f) y= $0.3m$

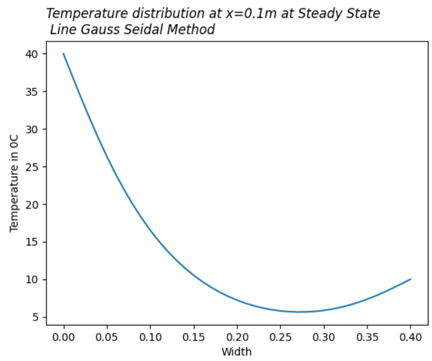


(g) y= $0.35m$

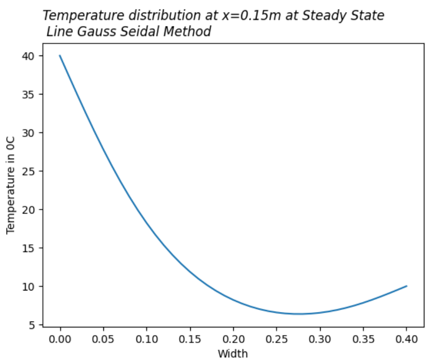
Figure 36: Point Gauss Seidal Method: Temperature vs Length(x) at Steady State



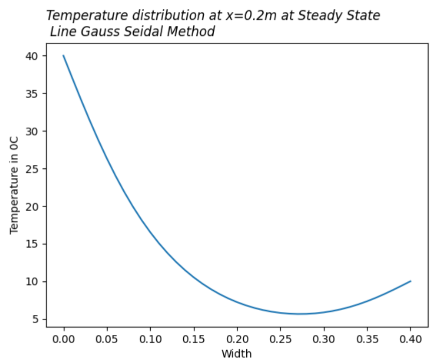
(a) x= $0.05m$



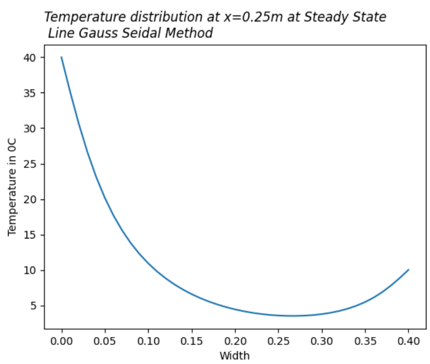
(b) x= $0.1m$



(c) x= $0.15m$

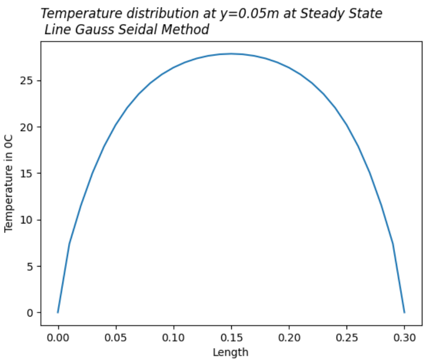


(d) x= $0.2m$

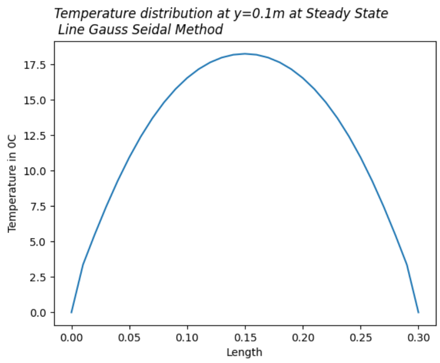


(e) x= $0.25m$

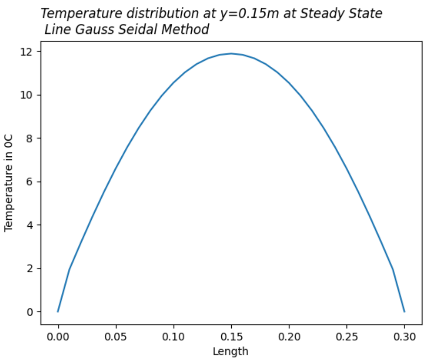
Figure 37: Line Gauss Seidal Method: Temperature vs Width(y) at Steady State



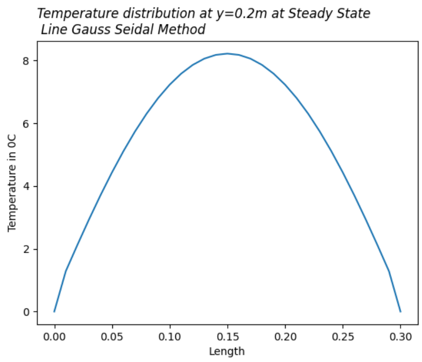
(a) y= $0.05m$



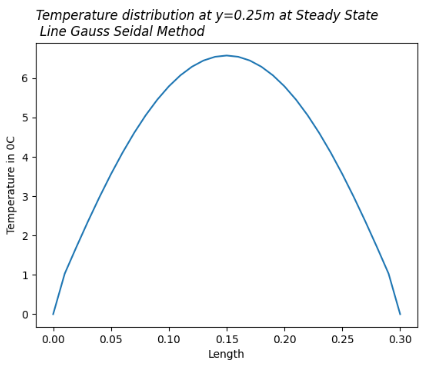
(b) y= $0.1m$



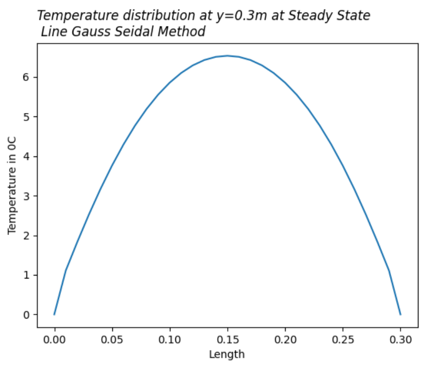
(c) y= $0.15m$



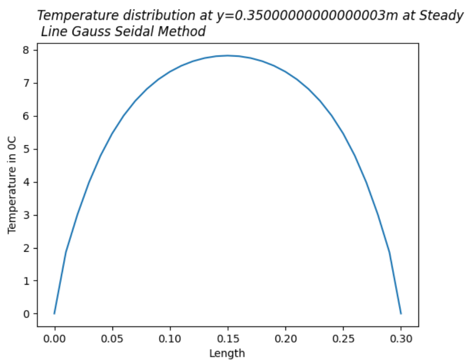
(d) y= $0.2m$



(e) y= $0.25m$

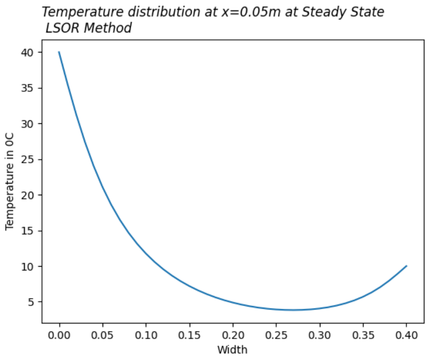


(f) y= $0.3m$

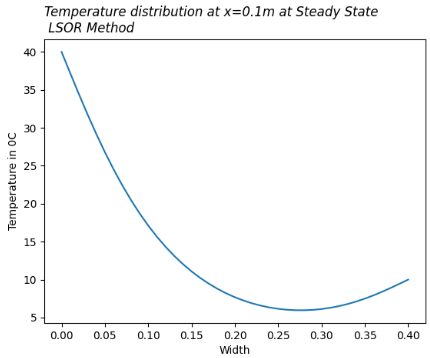


(g) y= $0.35m$

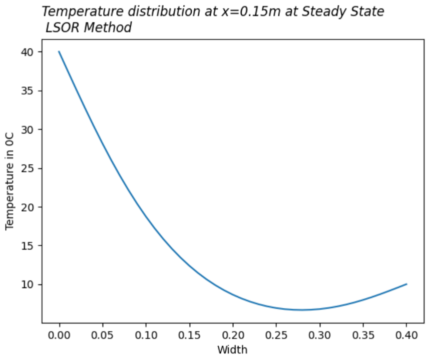
Figure 38: Line Gauss Seidal Method: Temperature vs Length(x) at Steady State



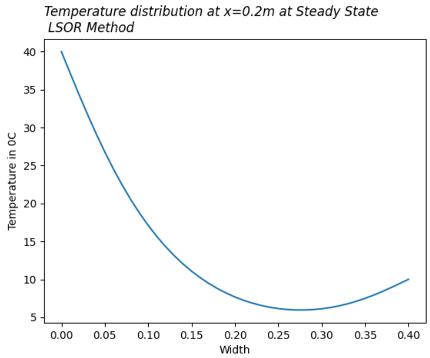
(a) x= $0.05m$



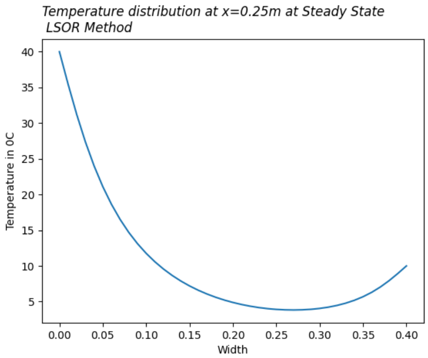
(b) x= $0.1m$



(c) x= $0.15m$

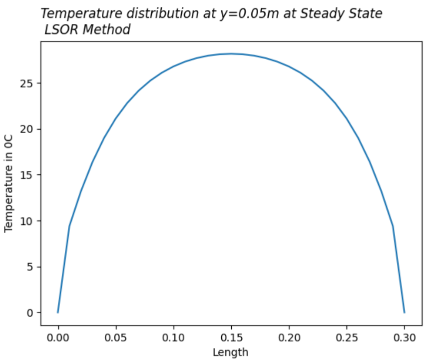


(d) x= $0.2m$

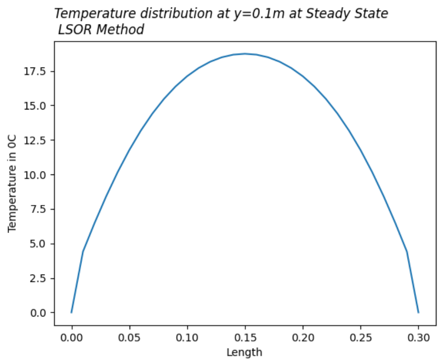


(e) x= $0.25m$

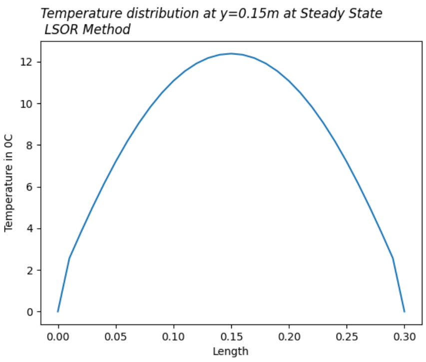
Figure 39: LSOR Method: Temperature vs Width(y) at Steady State



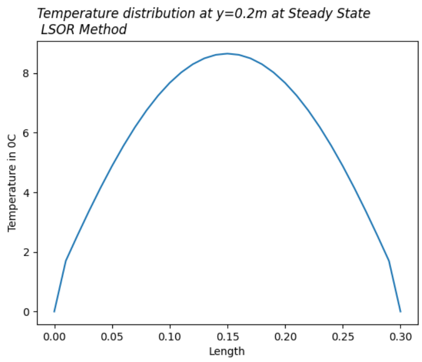
(a) y= $0.05m$



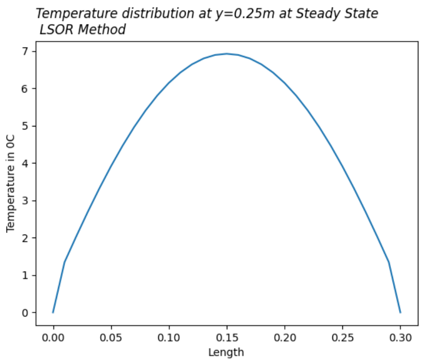
(b) y= $0.1m$



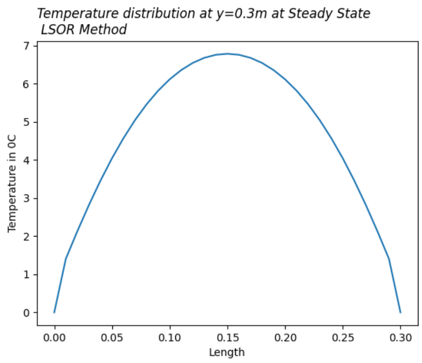
(c) y= $0.15m$



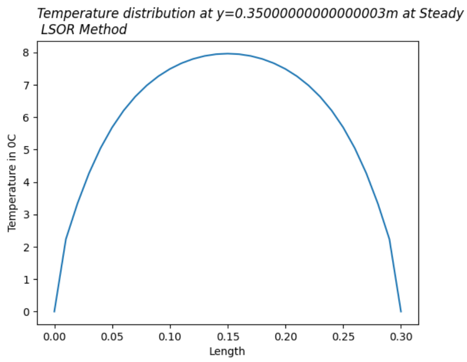
(d) y= $0.2m$



(e) y= $0.25m$

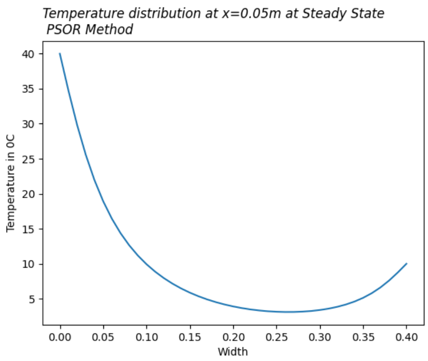


(f) y= $0.3m$

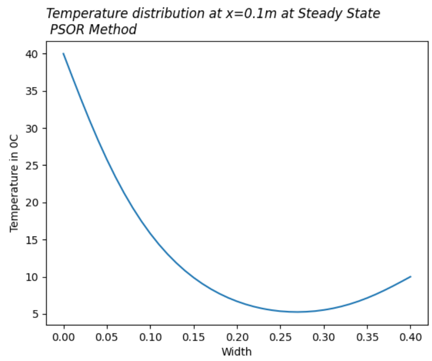


(g) y= $0.35m$

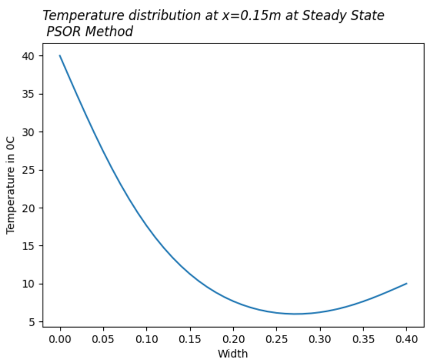
Figure 40: LSOR Method: Temperature vs Length(x) at Steady State



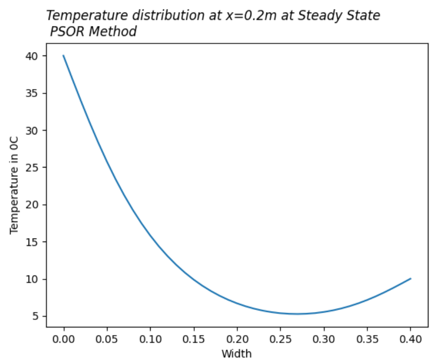
(a) x= $0.05m$



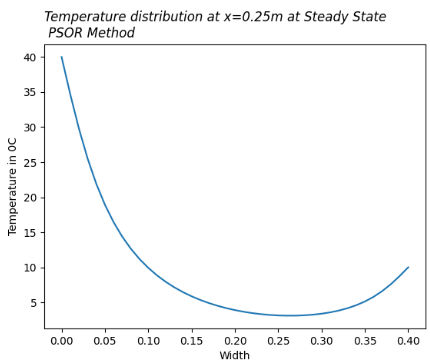
(b) x= $0.1m$



(c) x= $0.15m$

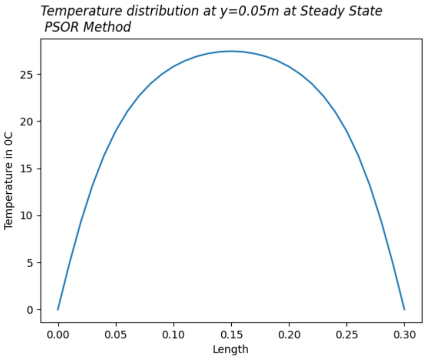


(d) x= $0.2m$

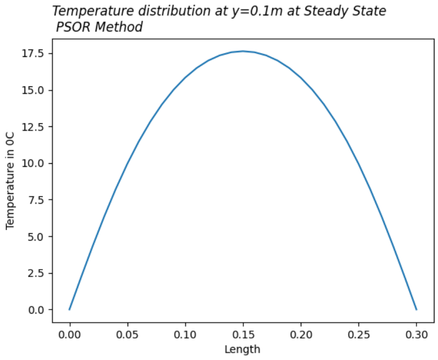


(e) x= $0.25m$

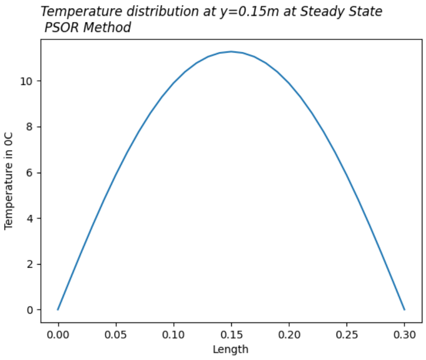
Figure 41: PSOR Method: Temperature vs Width(y) at Steady State



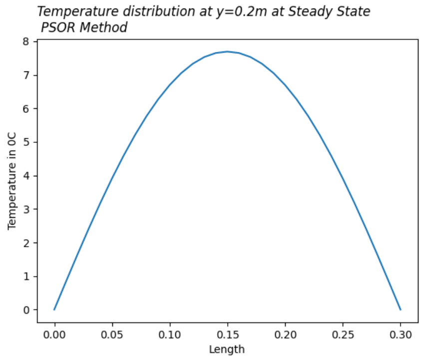
(a) y= $0.05m$



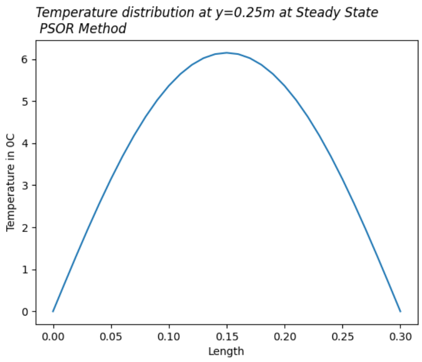
(b) y= $0.1m$



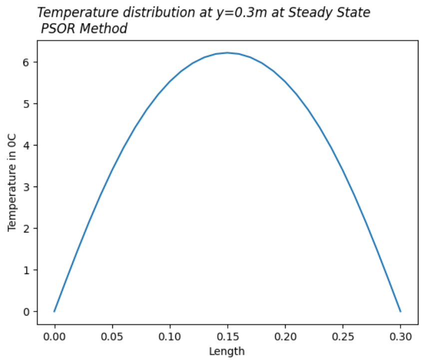
(c) y= $0.15m$



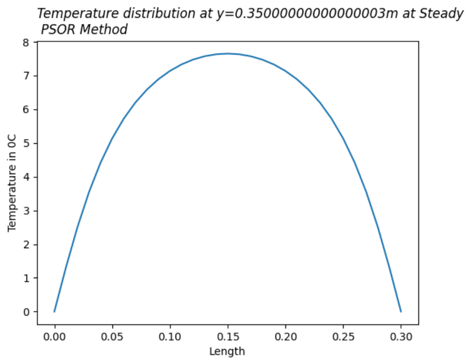
(d) y= $0.2m$



(e) y= $0.25m$



(f) y= $0.3m$



(g) y= $0.35m$

Figure 42: PSOR Method: Temperature vs Length(x) at Steady State