

1D, Cartesian, Homogeneous 1 Material Problem Description

PDE

$$\rho c_p \frac{\partial T}{\partial t} - \nabla k \nabla T = \rho c_p \frac{\partial T}{\partial t} - \frac{\partial}{\partial x} k \frac{\partial T}{\partial x} = q$$

Domain/Material Properties

$$\Omega_x = [0, 1], \quad \rho c_p = 10, \quad k = 1.5$$

BCs

Left: **Neumann** – $\left. \frac{\partial T}{\partial x} \right|_{x=0} = k \cdot 200t$
 Right: **Dirichlet** – $T(1, t) = 400$

IC

Constant – $T(x, 0) = 400$

Method of Manufactured Solutions for 1D, XY, Homogeneous Material Problem

Prescribed Solution

$$T(x, t) = (-200x + 200)t + 400$$

Derived Source

$$q = 200 \rho c_p (-x + 1)$$

Interface Level Set Function

$$\phi(x, t) = 1 - (x - 0.04) - 0.2t = 1.04 - x - 0.2t$$

Numerical Parameters

```

19 [GlobalParams]
20   order = FIRST
21   family = LAGRANGE
22   □
23
24 [Mesh]
25   type = GeneratedMesh
26   dim = 2
27   nx = 1
28   ny = 1
29   xmin = 0.0
30   xmax = 1.0
31   ymin = 0.0
32   ymax = 0.5
33   elem_type = QUAD4
34   □

```

```

147 [Executioner]
148   type = Transient
149   solve_type = 'PJFNK'
150   # petsc_options_iname = '-pc_type -pc_hypre_type'
151   # petsc_options_value = 'hypre boomeramg'
152   petsc_options_iname = '-pc_type'
153   petsc_options_value = 'lu'
154   line_search = 'none'
155
156   l_tol = 1.0e-6
157   nl_max_its = 15
158   nl_rel_tol = 1.0e-10
159   nl_abs_tol = 1.0e-9
160
161   start_time = 0.0
162   dt = 0.1
163   end_time = 2.0
164   max_xfem_update = 1
165   □

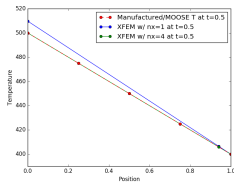
```

```

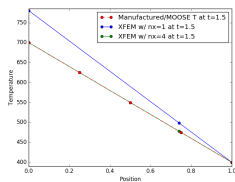
86 [Constraints]
87   [./xfem_constraint]
88     type = XFEMSingleVariableConstraint
89     variable = u
90     jump = 0
91     jump_flux = 0
92     geometric_cut_userobject = 'level_set_cut_uo'
93   [../]
94   □

```

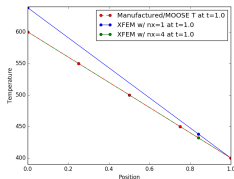
Results Comparison



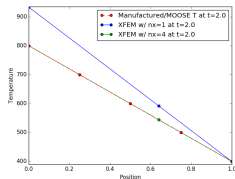
$t = 0.5$



$t = 1.5$

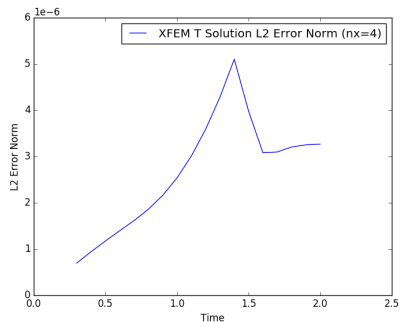
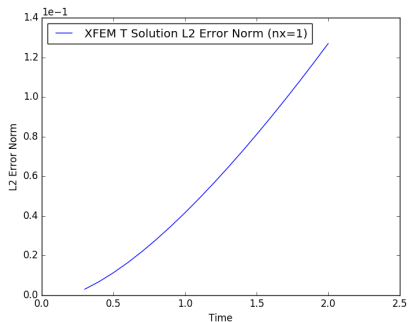


$t = 1.0$

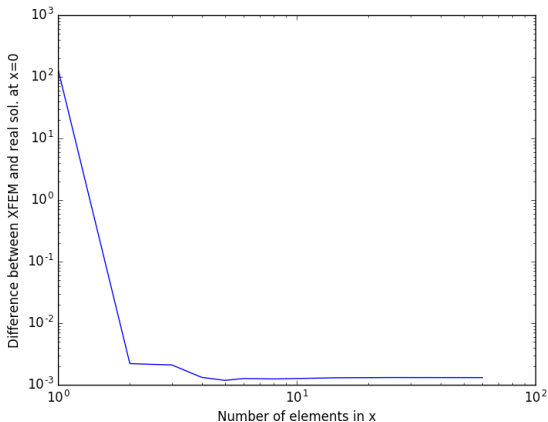


$t = 2.0$

L2 Error Norms at Each Timestep



Mesh Refinement Effects on Error at $x=0$



1D, Cartesian, Level Set Dependent Material Problem Description

PDE

$$\rho c_p \frac{\partial T}{\partial t} - \nabla k \nabla T = \rho c_p \frac{\partial T}{\partial t} - \frac{\partial}{\partial x} k \frac{\partial T}{\partial x} = q$$

Domain/Material Properties

$$\Omega_x = [0, 1], \quad \rho c_p = 10, \quad k = \left(\frac{0.05}{1.04} \right) \phi(x, t) + 1.5 = \frac{0.05}{1.04} (-x - 0.2t) + 1.55$$

BCs

Left: **Neumann** – $\frac{\partial T}{\partial x} \Big|_{x=0} = k(x, t) \cdot 200t$

Right: **Dirichlet** – $T(1, t) = 400$

IC

Constant – $T(x, 0) = 400$

Method of Manufactured Solutions for 1D, XY, LS Dependent Material Problem

Prescribed Solution

$$T(x, t) = (-200x + 200)t + 400$$

Derived Source

$$q = 200 \rho c_p (-x + 1) - \left(\frac{0.05 \cdot 200t}{1.04} \right)$$

Interface Level Set Function

$$\phi(x, t) = 1 - (x - 0.04) - 0.2t = 1.04 - x - 0.2t$$

Numerical Parameters

```

11 [GlobalParams]
12   order = FIRST
13   family = LAGRANGE
14   □
15
16 [Mesh]
17   type = GeneratedMesh
18   dim = 2
19   nx = 1
20   ny = 1
21   xmin = 0.0
22   xmax = 1.0
23   ymin = 0.0
24   ymax = 0.5
25   elem_type = QUAD4
26   □

```

```

145 [Executioner]
146   type = Transient
147   solve_type = 'PJFNK'
148   # petsc_options_iname = '-pc_type -pc_hypre_type'
149   # petsc_options_value = 'hypre boomeramg'
150   petsc_options_iname = '-pc_type'
151   petsc_options_value = 'lu'
152   line_search = 'none'
153
154   l_tol = 1.0e-6
155   nl_max_its = 15
156   nl_rel_tol = 1.0e-10
157   nl_abs_tol = 1.0e-9
158
159   start_time = 0.0
160   dt = 0.1
161   end_time = 2.0
162   max_xfem_update = 1
163   □

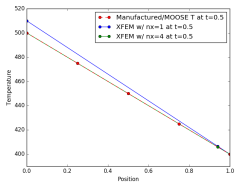
```

```

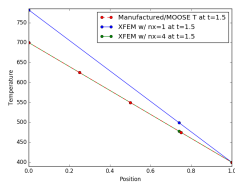
78 [Constraints]
79   [./xfem_constraint]
80     type = XFEMSingleVariableConstraint
81     variable = u
82     jump = 0
83     jump_flux = 0
84     geometric_cut_userobject = 'level_set_cut_uo'
85   [../]
86   □

```

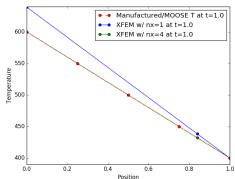
Results Comparison



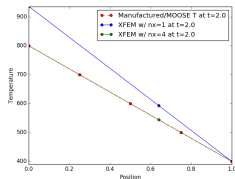
$t = 0.5$



$t = 1.5$

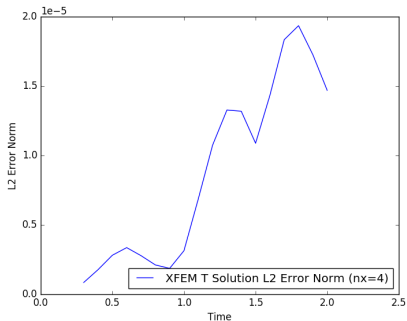
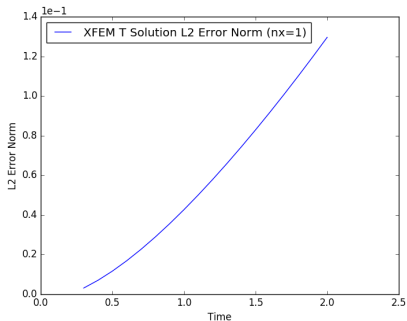


$t = 1.0$

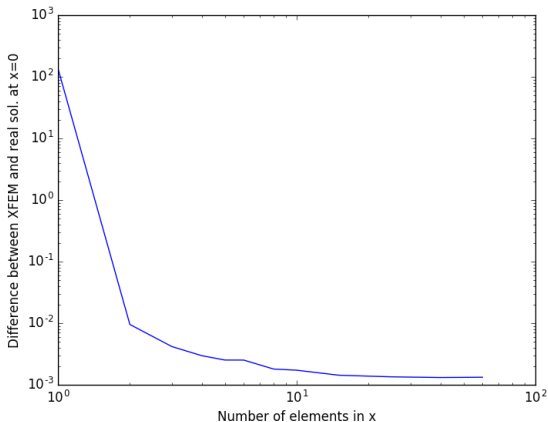


$t = 2.0$

L2 Error Norms at Each Timestep



Mesh Refinement Effects on Error at $x=0$



1D, Cylindrical, Homogeneous Material Problem Description

PDE

$$\rho c_p \frac{\partial T}{\partial t} - \nabla k \nabla T = \rho c_p \frac{\partial T}{\partial t} - \frac{1}{r} \frac{\partial}{\partial r} \left(r \cdot k \frac{\partial T}{\partial r} \right) = q$$

Domain/Material Properties

$$\Omega_r = [1, 2], \quad \rho c_p = 10, \quad k = 1.5$$

BCs

Left: **Neumann** – $\frac{\partial T}{\partial r} \Big|_{r=1} = k \cdot 200t$
 Right: **Dirichlet** – $T(2, t) = 400$

ICs

Constant – $T(r, 0) = 400$

Method of Manufactured Solutions for 1D, RZ, Homogeneous Material Problem

Prescribed Solution

$$T(r, t) = (-200r + 400)t + 400$$

Derived Source

$$q = 200 \rho c_p (-x + 2) + \frac{200kt}{r}$$

Interface Level Set Function

$$\phi(r, t) = 2 - (r - 0.04) - 0.2t = 2.04 - r - 0.2t$$

Numerical Parameters

```

11 [GlobalParams]
12   order = FIRST
13   family = LAGRANGE
14   □
15
16 [Problem]
17   coord_type = RZ
18   □
19
20 [Mesh]
21   type = GeneratedMesh
22   dim = 2
23   nx = 1
24   ny = 1
25   xmin = 1.0
26   xmax = 2.0
27   ymin = 0.0
28   ymax = 0.5
29   elem_type = QUAD4
30   □

```

```

143 [Executioner]
144   type = Transient
145   solve_type = 'PJFNK'
146   # Petsc_options_iname = '-pc_type -pc_hypre_type'
147   # Petsc_options_value = 'hypre boomeramg'
148   Petsc_options_iname = '-pc_type'
149   Petsc_options_value = 'lu'
150   line_search = 'none'
151
152   l_tol = 1.0e-6
153   nl_max_its = 15
154   nl_rel_tol = 1.0e-10
155   nl_abs_tol = 1.0e-9
156
157   start_time = 0.0
158   dt = 0.1
159   end_time = 2.0
160   max_xfem_update = 1
161   □

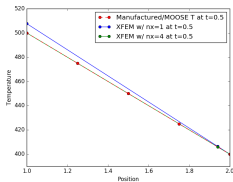
```

```

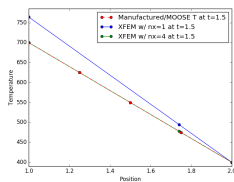
82 [Constraints]
83   [./xfem_constraint]
84     type = XFEMSingleVariableConstraint
85     variable = u
86     jump = 0
87     jump_flux = 0
88     geometric_cut_userobject = 'level_set_cut_uo'
89   [../]

```

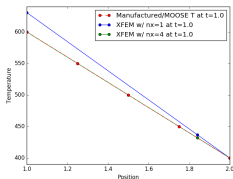
Results Comparison



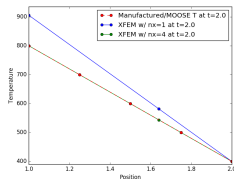
$t = 0.5$



$t = 1.5$

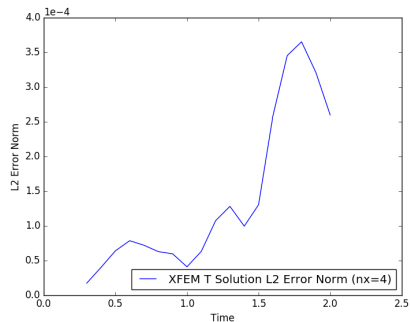
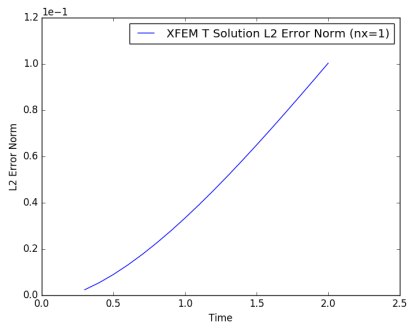


$t = 1.0$

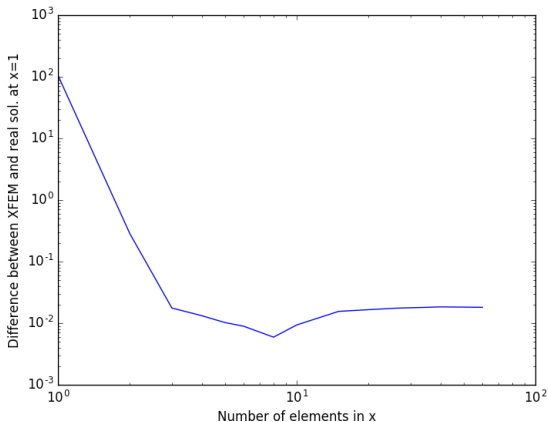


$t = 2.0$

L2 Error Norms at Each Timestep



Mesh Refinement Effects on Error at $x=1$



1D, Cylindrical, Level Set Dependent Material Problem Description

PDE

$$\rho c_p \frac{\partial T}{\partial t} - \nabla k \nabla T = \rho c_p \frac{\partial T}{\partial t} - \frac{1}{r} \frac{\partial}{\partial r} \left(r \cdot k \frac{\partial T}{\partial r} \right) = q$$

Domain/Material Properties

$$\Omega_r = [1, 2], \quad \rho c_p = 10, \quad k = \left(\frac{0.05}{2.04} \right) \phi(x, t) + 1.5 = \frac{0.05}{2.04} (-x - 0.2t) + 1.55$$

BCs

Left: **Neumann** - $\frac{\partial T}{\partial r} \Big|_{r=1} = k(r, t) \cdot 200t$
 Right: **Dirichlet** - $T(2, t) = 400$

ICs

Constant - $T(r, 0) = 400$

Method of Manufactured Solutions for 1D, RZ, LS Dependent Material Problem

Prescribed Solution

$$T(r, t) = (-200r + 400)t + 400$$

Derived Source

$$q = 200 \rho c_p (-x + 2) + \frac{1}{r} \left(310t - \frac{10rt}{1.02} - \frac{t^2}{1.02} \right)$$

Interface Level Set Function

$$\phi(r, t) = 2 - (r - 0.04) - 0.2t = 2.04 - r - 0.2t$$

Numerical Parameters

```

13 [GlobalParams]
14   order = FIRST
15   family = LAGRANGE
16   □
17
18 [Problem]
19   coord_type = RZ
20   □
21
22 [Mesh]
23   type = GeneratedMesh
24   dim = 2
25   nx = 1
26   ny = 1
27   xmin = 1.0
28   xmax = 2.0
29   ymin = 0.0
30   ymax = 0.5
31   elem_type = QUAD4
32   □

```

```

149 [Executioner]
150   type = Transient
151   solve_type = 'PJFNK'
152   # Petsc_options_iname = '-pc_type -pc_hypre_type'
153   # Petsc_options_value = 'hypre boomeramg'
154   Petsc_options_iname = '-pc_type'
155   Petsc_options_value = 'lu'
156   line_search = 'none'
157
158   l_tol = 1.0e-6
159   nl_max_its = 15
160   nl_rel_tol = 1.0e-10
161   nl_abs_tol = 1.0e-9
162
163   start_time = 0.0
164   dt = 0.1
165   end_time = 2.0
166   max_xfem_update = 1
167   □

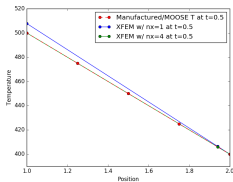
```

```

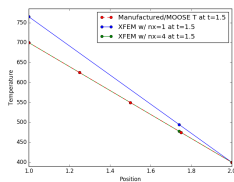
84 [Constraints]
85   [./xfem_constraint]
86   type = XFEMSingleVariableConstraint
87   variable = u
88   jump = 0
89   jump_flux = 0
90   geometric_cut_userobject = 'level_set_cut_uo'
91   □

```

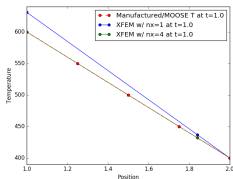
Results Comparison



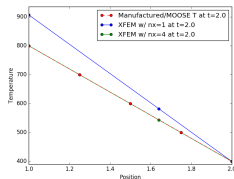
$t = 0.5$



$t = 1.5$

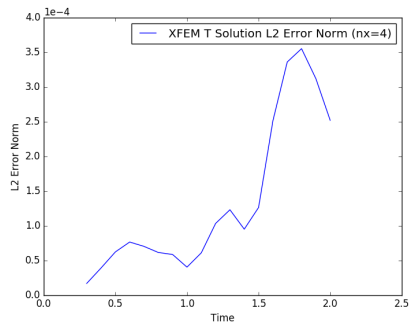
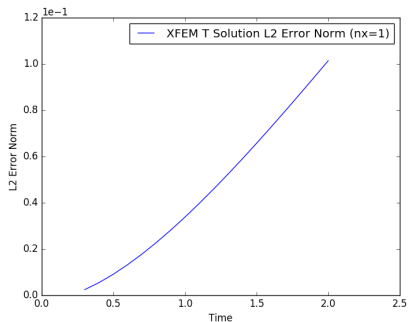


$t = 1.0$

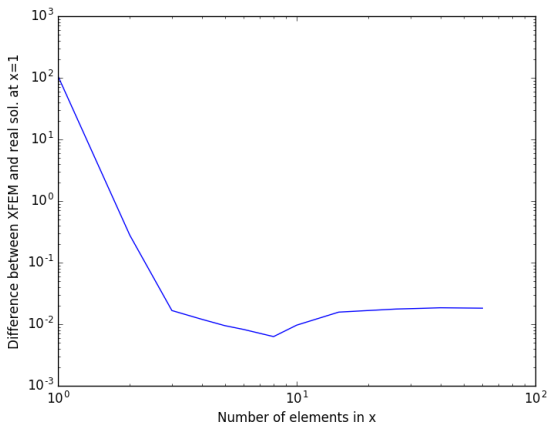


$t = 2.0$

L2 Error Norms at Each Timestep



Mesh Refinement Effects on Error at $x=1$



2D, Cartesian, Homogeneous Material Problem Description

PDE

$$\rho c_p \frac{\partial T}{\partial t} - \nabla k \nabla T = \rho c_p \frac{\partial T}{\partial t} - \frac{\partial}{\partial x} \left(k \frac{\partial T}{\partial x} \right) - \frac{\partial}{\partial y} \left(k \frac{\partial T}{\partial y} \right) = q$$

Domain/Material Properties

$$[\Omega_x, \Omega_y] = [[0, 1], [0, 1]]$$

$$\rho c_p = 10$$

$$k = 1.5$$

2D, Cartesian, Homogeneous Material Problem BCs/IC

BCs

Left: **Neumann** – $\frac{\partial T}{\partial x} \Big|_{x=0} = k \cdot 100t$

Right: **Dirichlet** - $T(1, y, t) = (-100y + 100)t + 400$

Bottom: **Neumann** - $\frac{\partial T}{\partial y} \Big|_{y=0} = k \cdot 100t$

Top: **Dirichlet** - $T(x, 1, t) = (-100x + 100)t + 400$

ICs

Constant – $T(x, y, 0) = 400$

Method of Manufactured Solutions for 2D, XY, Homogeneous Material Problem

Prescribed Solution

$$T(x, t) = (-100x - 100y + 200)t + 400$$

Derived Source

$$q = 100 \rho c_p (-x - y + 2)$$

Interface Level Set Function

$$\phi(x, y, t) = -0.5(x + y) + 1.04 - 0.2t$$

Numerical Parameters

```

14 [GlobalParams]
15   order = FIRST
16   family = LAGRANGE
17 □
18
19 [Mesh]
20   type = GeneratedMesh
21   dim = 2
22   nx = 1
23   ny = 1
24   xmin = 0.0
25   xmax = 1.0
26   ymin = 0.0
27   ymax = 1.0
28   elem_type = QUAD4
29 □

```

```

162 [Executioner]
163   type = Transient
164   solve_type = 'PJFNK'
165   # petsc_options_iname = '-pc_type -pc_hypre_type'
166   # petsc_options_value = 'hypre boomeramg'
167   petsc_options_iname = '-pc_type'
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169   line_search = 'none'
170
171   l_tol = 1.0e-6
172   nl_max_its = 15
173   nl_rel_tol = 1.0e-10
174   nl_abs_tol = 1.0e-9
175
176   start_time = 0.0
177   dt = 0.1
178   end_time = 2.0
179   max_xfem_update = 1
180 □

```

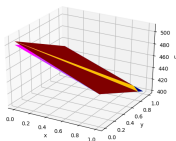
```

81 [Constraints]
82   [./xfem_constraints]
83     type = XFEMSingleVariableConstraint
84     variable = u
85     jump = 0
86     jump_flux = 0
87     geometric_cut_userobject = 'level_set_cut_uo'
88   [../]
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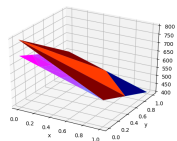
```

Results Comparison

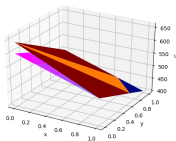
Upper plane is $n_x=1$, $n_y=1$; lower plane is $n_x=4$, $n_y=4$



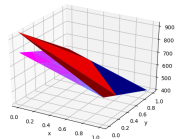
$t = 0.5$



$t = 1.5$

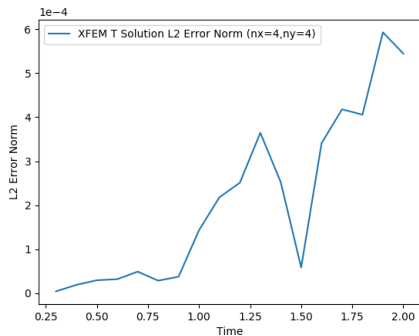
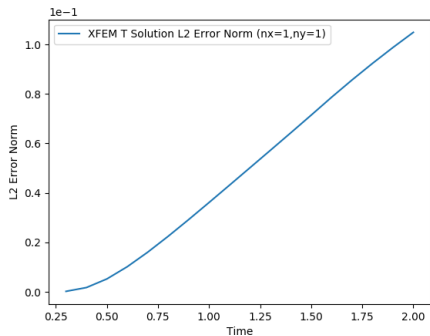


$t = 1.0$

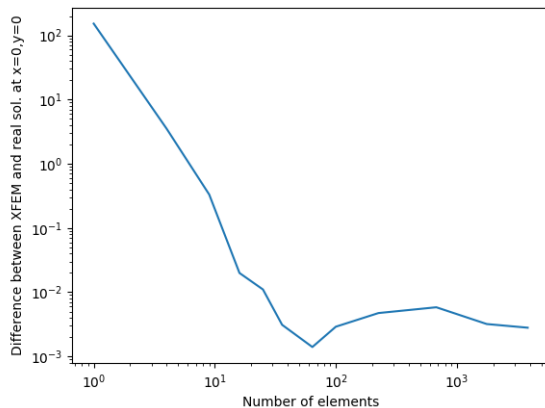


$t = 2.0$

L2 Error Norms at Each Timestep



Mesh Refinement Effects on Error at $x=0, y=0$



2D, Cartesian, Level Set Dependent Material Problem Description

PDE

$$\rho c_p \frac{\partial T}{\partial t} - \nabla k \nabla T = \rho c_p \frac{\partial T}{\partial t} - \frac{\partial}{\partial x} \left(k \frac{\partial T}{\partial x} \right) - \frac{\partial}{\partial y} \left(k \frac{\partial T}{\partial y} \right) = q$$

Domain/Material Properties

$$[\Omega_x, \Omega_y] = [[0, 1], [0, 1]]$$

$$\rho c_p = 10$$

$$k(x, y, t) = \left(\frac{0.05}{1.04} \right) \phi(x, y, t) + 1.5 = \left(\frac{0.01}{1.04} \right) (-2.5x - 2.5y - t) + 1.55$$

2D, Cartesian, Level Set Dependent Material Problem BCs/IC

BCs

Left: **Neumann** - $\frac{\partial T}{\partial x} \Big|_{x=0} = k(x, y, t) \cdot 100t$

Right, Top: **Dirichlet** - $T(1, y, t) = (-100y + 100)t + 400$

Bottom: **Neumann** - $\frac{\partial T}{\partial y} \Big|_{y=0} = k(x, y, t) \cdot 100t$

Top: **Dirichlet** - $T(x, 1, t) = (-100x + 100)t + 400$

ICs

Constant - $T(x, y, 0) = 400$

Method of Manufactured Solutions for 2D, XY, LS Dependent Material Problem

Prescribed Solution

$$T(x, t) = (-100x - 100y + 200)t + 400$$

Derived Source

$$q = 100 \rho c_p (-x - y + 2) - \frac{5t}{1.04}$$

Interface Level Set Function

$$\phi(x, y, t) = -0.5(x + y) + 1.04 - 0.2t$$

Numerical Parameters

```

11 [GlobalParams]
12   order = FIRST
13   family = LAGRANGE
14   □
15
16 [Mesh]
17   type = GeneratedMesh
18   dim = 2
19   nx = 1
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21   xmin = 0.0
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23   ymin = 0.0
24   ymax = 1.0
25   elem_type = QUAD4
26   □
    
```

```

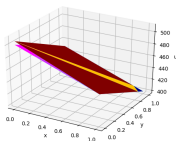
163 [Executioner]
164   type = Transient
165   solve_type = 'PJFNK'
166   # petsc_options_iname = '-pc_type -pc_hypre_type'
167   # petsc_options_value = 'hypre boomeramg'
168   petsc_options_iname = '-pc_type'
169   petsc_options_value = 'lu'
170   line_search = 'none'
171
172   l_tol = 1.0e-6
173   nl_max_its = 15
174   nl_rel_tol = 1.0e-10
175   nl_abs_tol = 1.0e-9
176
177   start_time = 0.0
178   dt = 0.1
179   end_time = 2.0
180   max_xfem_update = 1
181   □
    
```

```

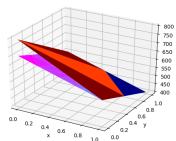
78 [Constraints]
79   [./xfem_constraints]
80     type = XFEMSingleVariableConstraint
81     variable = u
82     jump = 0
83     jumpflux = 0
84     geometric_cut_userobject = 'level_set_cut_uo'
85   [../]
86   □
    
```

Results Comparison

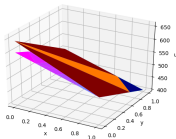
Upper plane is $n_x=1$, $n_y=1$; lower plane is $n_x=4$, $n_y=4$



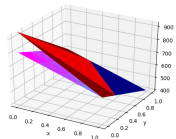
$t = 0.5$



$t = 1.5$

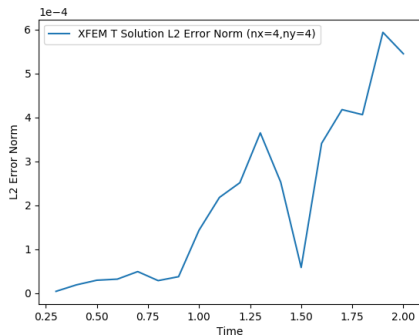
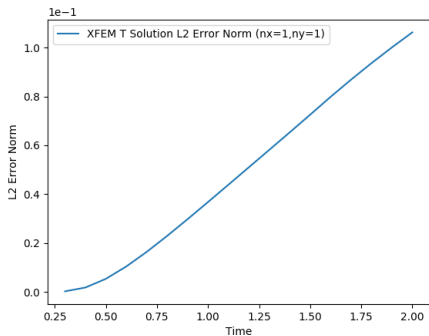


$t = 1.0$

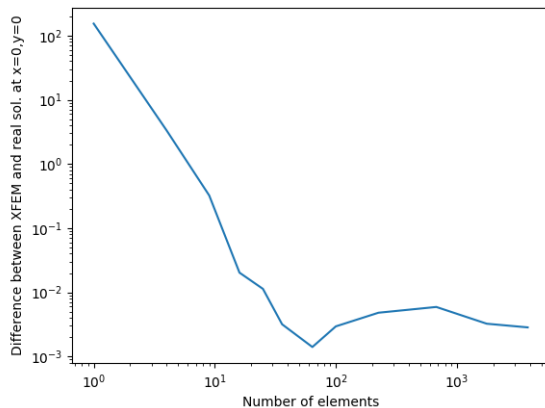


$t = 2.0$

L2 Error Norms at Each Timestep



Mesh Refinement Effects on Error at $x=0$



2D, Cylindrical, Homogeneous Material Problem Description

PDE

$$\rho c_p \frac{\partial T}{\partial t} - \nabla k \nabla T = \rho c_p \frac{\partial T}{\partial t} - \frac{1}{r} \frac{\partial}{\partial r} \left(r \cdot k \frac{\partial T}{\partial r} \right) - \frac{\partial}{\partial z} \left(k \frac{\partial T}{\partial z} \right) = q$$

Domain/Material Properties

$$[\Omega_r, \Omega_z] = [[1, 2], [1, 2]]$$

$$\rho c_p = 10$$

$$k = 1.5$$

2D, Cylindrical, Homogeneous Problem BCs/IC

BCs

Left: **Neumann** – $\frac{\partial T}{\partial r} \Big|_{r=1} = k \cdot 100t$

Right: **Dirichlet** – $T(2, z, t) = (-100z + 200)t + 400$

Bottom: **Neumann** – $\frac{\partial T}{\partial z} \Big|_{z=1} = k \cdot 100t$

Top: **Dirichlet** – $T(r, 2, t) = (-100r + 200)t + 400$

ICs

Constant – $T(r, z, 0) = 400$

Method of Manufactured Solutions for 2D, RZ, Homogeneous Material Problem

Prescribed Solution

$$T(x, t) = (-100r - 100z + 400)t + 400$$

Derived Source

$$q = 100 \rho c_p (-r - z + 4) + \frac{100kt}{r}$$

Interface Level Set Function

$$\phi(x, y, t) = -0.5(x + y) + 2.04 - 0.2t$$

Numerical Parameters

```

11 [GlobalParams]
12   order = FIRST
13   family = LAGRANGE
14   □
15
16 [Problem]
17   coord_type = RZ
18   □
19
20 [Mesh]
21   type = GeneratedMesh
22   dim = 2
23   nx = 1
24   ny = 1
25   xmin = 1.0
26   xmax = 2.0
27   ymin = 1.0
28   ymax = 2.0
29   elem_type = QUAD4
30   □

```

```

163 [Executioner]
164   type = Transient
165   solve_type = 'PJFKNK'
166   # Petsc_options_iname = '-pc_type -pc_hypre_type'
167   # Petsc_options_value = 'hypre boomeramg'
168   Petsc_options_iname = '-pc_type'
169   Petsc_options_value = 'lu'
170   line_search = 'none'
171
172   l_tol = 1.0e-6
173   nl_max_its = 15
174   nl_rel_tol = 1.0e-10
175   nl_abs_tol = 1.0e-9
176
177   start_time = 0.0
178   dt = 0.1
179   end_time = 2.0
180   max_xfem_update = 1
181   □

```

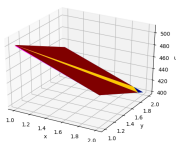
```

82 [Constraints]
83   [./xfem_constraints]
84     type = XFEMSingleVariableConstraint
85     variable = u
86     jump = 0
87     jump_flux = 0
88     geometric_cut_userobject = 'level_set_cut_uo'
89   [../]

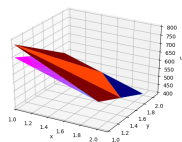
```

Results Comparison

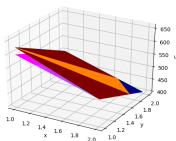
Upper plane is $n_x=1$, $n_y=1$; lower plane is $n_x=4$, $n_y=4$



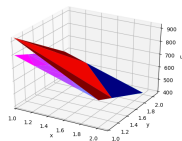
$t = 0.5$



$t = 1.5$

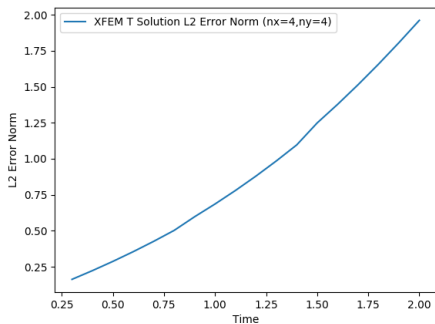
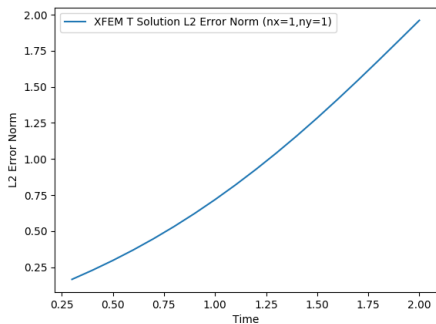


$t = 1.0$

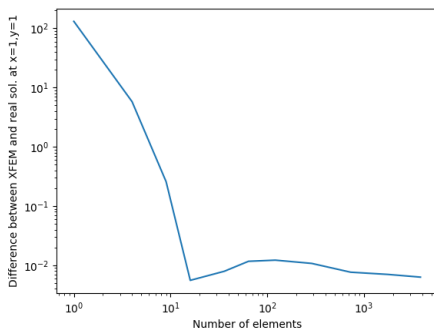


$t = 2.0$

L2 Error Norms at Each Timestep



Mesh Refinement Effects on Error at $x=1, y=1$



2D, Cylindrical, Level Set Dependent Material Problem Description

PDE

$$\rho c_p \frac{\partial T}{\partial t} - \nabla k \nabla T = \rho c_p \frac{\partial T}{\partial t} - \frac{1}{r} \frac{\partial}{\partial r} \left(r \cdot k \frac{\partial T}{\partial r} \right) - \frac{\partial}{\partial z} \left(k \frac{\partial T}{\partial z} \right) = q$$

Domain/Material Properties

$$[\Omega_r, \Omega_z] = [[1, 2], [1, 2]]$$

$$\rho c_s p = 10$$

$$k(r, z, t) = \left(\frac{0.05}{2.04} \right) \phi(r, z, t) + 1.5 = -\frac{0.025}{2.04} (r + z) + 1.55 - \frac{0.01t}{2.04}$$

2D, Cylindrical, Level Set Dependent Material Problem

BCs

Left: **Neumann** - $\frac{\partial T}{\partial r}\bigg|_{r=1} = k(r, z, t) \cdot 100t$

Right: **Dirichlet** - $T(2, z, t) = (-100z + 200)t + 400$

Bottom: **Neumann** - $\frac{\partial T}{\partial z} \Big|_{z=1} = k(r, z, t) \cdot 100t$

Top: **Dirichlet** - $T(r, 2, t) = (-100r + 200)t + 400$

ICs

Constant – $T(r, z, 0) = 400$

Method of Manufactured Solutions for 2D, RZ, LS Dependent Material Problem

Prescribed Solution

$$T(x, t) = (-100r - 100z + 400)t + 400$$

Derived Source

$$q = 100 \rho c_p (-r - z + 4) + t \left(-\frac{2.5}{2.04} \frac{z}{r} + 155 \frac{1}{r} + \frac{1}{2.04} \frac{t}{r} - \frac{7.5}{2.04} \right)$$

Interface Level Set Function

$$\phi(x, y, t) = -0.5(x + y) + 2.04 - 0.2t$$

Numerical Parameters

```

11 [GlobalParams]
12   order = FIRST
13   family = LAGRANGE
14   □
15
16 [Problem]
17   coord_type = RZ
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20 [Mesh]
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26   xmax = 2.0
27   ymin = 1.0
28   ymax = 2.0
29   elem_type = QUAD4
30   □

```

```

168 [Executioner]
169   type = Transient
170   solve_type = 'PJFNK'
171   # Petsc_options_iname = '-pc_type -pc_hypre_type'
172   # Petsc_options_value = 'hypre boomeramg'
173   Petsc_options_iname = '-pc_type'
174   Petsc_options_value = 'lu'
175   line_search = 'none'
176
177   l_tol = 1.0e-6
178   nl_max_its = 15
179   nl_rel_tol = 1.0e-10
180   nl_abs_tol = 1.0e-9
181
182   start_time = 0.0
183   dt = 0.1
184   end_time = 2.0
185   max_xfem_update = 1
186   □

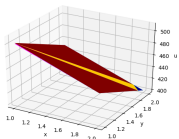
```

```

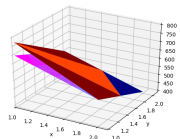
82 [Constraints]
83   [./xfem_constraint]
84     type = XFEMSingleVariableConstraint
85     variable = u
86     jump = 0
87     jump_flux = 0
88     geometric_cut_userobject = 'level_set_cut_uo'
89   [../]

```

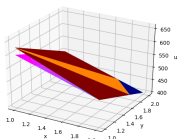
Results Comparison



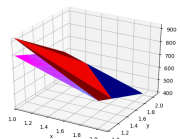
$t = 0.5$



$t = 1.5$

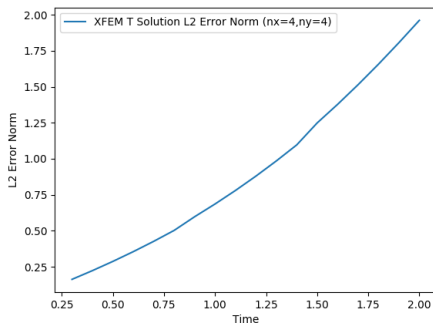
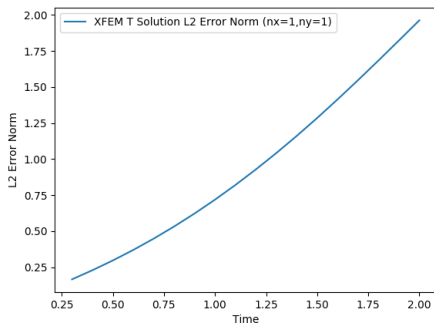


$t = 1.0$



$t = 2.0$

L2 Error Norms at Each Timestep



Mesh Refinement Effects on Error at $x=1, y=1$

