西安交通大学实验报告

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| 成绩 |  |

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| 课程： |  | | | 实验日期 | 年　　月　　日 |
| 专业班号 |  | 组别 |  | 交报告日期 | 年　　月　　日 |
| 姓名 |  | 学号 |  | 报告退发 | （订正、重做） |
| 同组者 |  | | | 教室审批签字 |  |

# 二维导热物体温度场的计算机模拟实验

实验名称

## 一、实验目的

1. 学习电、热类比的原理及边界条件的处理；
2. 通过计算机编程的方式求出墙角导热的离散温度场。

## 二、实验原理

二维稳态过程，导热方程为

二维稳态导热内部节点的差分方程为

于是内部节点的迭代计算式为

对于恒温边界条件，除了绝热边界时使用对称性外，只使用上面一个迭代计算式即可。但是对于对流边界，边界上的点，按位置分为内角点、外角点和平直边界，按类型分为对流边界、绝热边界，计算步骤相比恒温边界下更为复杂。

按位置：

1. 内角点：4个方向均有导热热流，有面积的对流换热
2. 外角点：2个方向有导热，有面积的对流换热
3. 平直边界：3个方向有导热，有或面积的对流换热

按类型：

1. 绝热边界：该点的绝热一侧没有热流量，基尔霍夫定律中，此方向的热流量代入0计算
2. 对流边界：该点该方向的对流换热量由牛顿冷却公式计算得出

综上所述：

对流边界下的差分方程为：

其中，为导热量，为对流边界换热量。，。

代入所有的计算式，可解得

注意：

1. 为实际参与导热的几个方向，对于内角点有4项，外角点有2项，平直边界有3项，绝热边界还要去掉这一方向的那一项
2. 的值根据实际位置确定，内角点得两个方向为两个方向为,外角点的两个方向均为，平直边界有两个和一个
3. 内外测流体的不相等，对流面积为该网格实际与流体接触的面积角点为，平直边界为。

具体代码参见附录。

## 三、实验数据的整理

根据得到的温度场分布图，计算单位厚度墙体换热量（W/m），如下表所示：

|  |  |  |
| --- | --- | --- |
| 恒温边界 | 外表面 | 60.42871112 |
| 内表面 | 60.42871112 |
| 对流边界 | 外表面 | 28.36094047 |
| 内表面 | 28.36094047 |

可以看出计算机模拟法的精确度是足够高的

## 四、附录

### 1. 实验数据

#### 1.1 恒温边界：外温，内温

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 | 30.00 |
| 30.00 | 29.03 | 28.07 | 27.12 | 26.22 | 25.46 | 24.89 | 24.53 | 24.30 | 24.17 | 24.09 | 24.05 | 24.03 | 24.02 | 24.01 | 24.01 |
| 30.00 | 28.07 | 26.12 | 24.18 | 22.31 | 20.71 | 19.60 | 18.91 | 18.51 | 18.28 | 18.15 | 18.08 | 18.05 | 18.03 | 18.02 | 18.01 |
| 30.00 | 27.12 | 24.18 | 21.16 | 18.14 | 15.46 | 13.87 | 13.00 | 12.54 | 12.29 | 12.16 | 12.09 | 12.05 | 12.03 | 12.02 | 12.01 |
| 30.00 | 26.22 | 22.31 | 18.14 | 13.64 | 9.13 | 7.42 | 6.70 | 6.36 | 6.19 | 6.10 | 6.05 | 6.03 | 6.02 | 6.01 | 6.01 |
| 30.00 | 25.46 | 20.71 | 15.47 | 9.13 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| 30.00 | 24.90 | 19.60 | 13.88 | 7.43 | 0.00 |  |  |  |  |  |  |  |  |  |  |
| 30.00 | 24.53 | 18.92 | 13.01 | 6.70 | 0.00 |  |  |  |  |  |  |  |  |  |  |
| 30.00 | 24.31 | 18.52 | 12.55 | 6.36 | 0.00 |  |  |  |  |  |  |  |  |  |  |
| 30.00 | 24.18 | 18.30 | 12.32 | 6.20 | 0.00 |  |  |  |  |  |  |  |  |  |  |
| 30.00 | 24.12 | 18.20 | 12.20 | 6.13 | 0.00 |  |  |  |  |  |  |  |  |  |  |
| 30.00 | 24.10 | 18.17 | 12.17 | 6.11 | 0.00 |  |  |  |  |  |  |  |  |  |  |

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| --- | --- |
| C:\Users\Ganlv\AppData\Local\Microsoft\Windows\INetCache\Content.Word\恒温边界等温线.png  等温曲线图 | C:\Users\Ganlv\AppData\Local\Microsoft\Windows\INetCache\Content.Word\恒温边界.png  三维图像 |

#### 1.2对流边界：外温，内温

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| 29.90 | 29.71 | 29.52 | 29.33 | 29.15 | 28.99 | 28.86 | 28.75 | 28.68 | 28.63 | 28.60 | 28.58 | 28.56 | 28.55 | 28.55 | 28.55 |
| 29.71 | 29.14 | 28.56 | 27.99 | 27.45 | 26.96 | 26.55 | 26.25 | 26.03 | 25.88 | 25.79 | 25.72 | 25.68 | 25.66 | 25.65 | 25.64 |
| 29.52 | 28.56 | 27.60 | 26.63 | 25.69 | 24.84 | 24.15 | 23.65 | 23.31 | 23.09 | 22.94 | 22.85 | 22.79 | 22.76 | 22.74 | 22.73 |
| 29.33 | 27.99 | 26.63 | 25.24 | 23.84 | 22.55 | 21.57 | 20.90 | 20.48 | 20.21 | 20.04 | 19.94 | 19.87 | 19.84 | 19.82 | 19.81 |
| 29.15 | 27.45 | 25.69 | 23.85 | 21.90 | 19.95 | 18.66 | 17.91 | 17.48 | 17.23 | 17.08 | 16.99 | 16.93 | 16.90 | 16.88 | 16.88 |
| 28.99 | 26.96 | 24.84 | 22.56 | 19.96 | 16.70 | 15.20 | 14.61 | 14.31 | 14.15 | 14.06 | 14.00 | 13.96 | 13.94 | 13.93 | 13.93 |
| 28.86 | 26.56 | 24.17 | 21.58 | 18.67 | 15.21 |  |  |  |  |  |  |  |  |  |  |
| 28.76 | 26.26 | 23.68 | 20.93 | 17.93 | 14.62 |  |  |  |  |  |  |  |  |  |  |
| 28.69 | 26.06 | 23.35 | 20.52 | 17.52 | 14.34 |  |  |  |  |  |  |  |  |  |  |
| 28.65 | 25.93 | 23.15 | 20.28 | 17.29 | 14.19 |  |  |  |  |  |  |  |  |  |  |
| 28.62 | 25.85 | 23.04 | 20.15 | 17.17 | 14.11 |  |  |  |  |  |  |  |  |  |  |
| 28.61 | 25.83 | 23.00 | 20.11 | 17.14 | 14.09 |  |  |  |  |  |  |  |  |  |  |

|  |  |
| --- | --- |
| 等温曲线图 | C:\Users\Ganlv\AppData\Local\Microsoft\Windows\INetCache\Content.Word\对流边界.png  三维图像 |

### 2. 计算程序源代码

#### 2.1 Python源代码

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| # python main.py # 恒温边界  # python main.py convection # 对流边界  import numpy as np  from mpl\_toolkits.mplot3d import Axes3D  import matplotlib.pyplot as plt  from matplotlib import cm  from matplotlib.ticker import LinearLocator, FormatStrFormatter  import sys  X = np.arange(0, 16)  Y = np.arange(0, 12)  X, Y = np.meshgrid(Y, X)  fig = plt.figure()  ax = fig.add\_subplot(1, 1, 1)  # ax = fig.gca(projection='3d')  t = np.zeros((16, 12))  conduction = True  for i in sys.argv:  if i == 'convection':  conduction = False  break  h1 = 10.6  lam = 0.53  dx = 0.1  lambda\_over\_dx = lam / dx  h2 = 3.975  if conduction:  t1 = 30  t2 = 0  t[0, :] = t1  t[:, 0] = t1  t[5:16, 5:12] = t2  else:  t1 = 30  t2 = 10  t[0, :] = t1  t[:, 0] = t1  t[5:16, 5:12] = t2  if conduction:  for k in range(0, 1000):  for m in range(1, 5):  for n in range(1, 11):  t[m, n] = (t[m - 1, n] + t[m + 1, n] + t[m, n - 1] + t[m, n + 1]) / 4  n = 11  t[m, n] = (t[m - 1, n] + t[m + 1, n] + t[m, n - 1] \* 2) / 4  for m in range(5, 15):  for n in range(1, 5):  t[m, n] = (t[m - 1, n] + t[m + 1, n] + t[m, n - 1] + t[m, n + 1]) / 4  m = 15  for n in range(1, 5):  t[m, n] = (t[m - 1, n] \* 2 + t[m, n - 1] + t[m, n + 1]) / 4  else:  for k in range(0, 1000):  # m = 0  m = 0  n = 0  t[m, n] = (h1 \* t1 + lambda\_over\_dx \* (t[m + 1, n] / 2 + t[m, n + 1] / 2)) / (h1 + lambda\_over\_dx)  for n in range(1, 11):  t[m, n] = (h1 \* t1 + lambda\_over\_dx \* (t[m + 1, n] + t[m, n - 1] / 2 + t[m, n + 1] / 2)) / (h1 + lambda\_over\_dx \* 2)  n = 11  t[m, n] = (h1 \* t1 / 2 + lambda\_over\_dx \* (t[m + 1, n] / 2 + t[m, n - 1] / 2)) / (h1 / 2 + lambda\_over\_dx)  # m = 1 .. 4  for m in range(1, 5):  n = 0  t[m, n] = (h1 \* t1 + lambda\_over\_dx \* (t[m - 1, n] / 2 + t[m + 1, n] / 2 + t[m, n + 1])) / (h1 + lambda\_over\_dx \* 2)  for n in range(1, 11):  t[m, n] = (t[m - 1, n] + t[m + 1, n] + t[m, n - 1] + t[m, n + 1]) / 4  n = 11  t[m, n] = (t[m - 1, n] / 2 + t[m + 1, n] / 2 + t[m, n - 1]) / 2  # m = 5  m = 5  n = 0  t[m, n] = (h1 \* t1 + lambda\_over\_dx \* (t[m - 1, n] / 2 + t[m + 1, n] / 2 + t[m, n + 1])) / (h1 + lambda\_over\_dx \* 2)  for n in range(1, 5):  t[m, n] = (t[m - 1, n] + t[m + 1, n] + t[m, n - 1] + t[m, n + 1]) / 4  n = 5  t[m, n] = (h2 \* t2 + lambda\_over\_dx \* (t[m - 1, n] + t[m + 1, n] / 2 + t[m, n - 1] + t[m, n + 1] / 2)) / (h2 + lambda\_over\_dx \* 3)  for n in range(6, 11):  t[m, n] = (h2 \* t2 + lambda\_over\_dx \* (t[m - 1, n] + t[m, n - 1] / 2 + t[m, n + 1] / 2)) / (h2 + lambda\_over\_dx \* 2)  n = 11  t[m, n] = (h2 \* t2 / 2 + lambda\_over\_dx \* (t[m - 1, n] / 2 + t[m, n - 1] / 2)) / (h2 / 2 + lambda\_over\_dx)  # m = 6 .. 14  for m in range(6, 15):  n = 0  t[m, n] = (h1 \* t1 + lambda\_over\_dx \* (t[m - 1, n] / 2 + t[m + 1, n] / 2 + t[m, n + 1])) / (h1 + lambda\_over\_dx \* 2)  for n in range(1, 5):  t[m, n] = (t[m - 1, n] + t[m + 1, n] + t[m, n - 1] + t[m, n + 1]) / 4  n = 5  t[m, n] = (h2 \* t2 + lambda\_over\_dx \* (t[m - 1, n] / 2 + t[m + 1, n] / 2 + t[m, n - 1])) / (h2 + lambda\_over\_dx \* 2)  # m = 15  m = 15  n = 0  t[m, n] = (h1 \* t1 / 2 + lambda\_over\_dx \* (t[m - 1, n] / 2 + t[m, n + 1] / 2)) / (h1 / 2 + lambda\_over\_dx)  for n in range(1, 5):  t[m, n] = (t[m - 1, n] + t[m, n - 1] / 2 + t[m, n + 1] / 2) / 2  n = 5  t[m, n] = (h2 \* t2 / 2 + lambda\_over\_dx \* (t[m - 1, n] / 2 + t[m, n - 1] / 2)) / (h2 / 2 + lambda\_over\_dx)  # surf = ax.plot\_surface(X, Y, t, cmap=cm.coolwarm, linewidth=0, antialiased=False)  ax.pcolormesh(X, Y, t, cmap=cm.coolwarm)  if conduction:  ax.contour(X, Y, t, [12, 18, 24])  else:  ax.contour(X, Y, t, [18, 22, 26])  plt.show()  t = np.transpose(t)  if conduction:  np.savetxt("conduction.csv", t, delimiter=",")  else:  np.savetxt("convection.csv", t, delimiter=",") |

#### 2.2 运行方法：

计算恒温边界：执行python main.py

计算对流边界：执行python main.py convection