Natural_convection_open

July 29, 2023

[1]:
```python
import numpy as np
import matplotlib.pyplot as plt
```

[5]:
```python
##Number of lattice points in x and y direction
Nx=60
Ny=60
##grid spacing
x=np.linspace(0,1,Nx)
y=np.linspace(0,1,Ny)
[X,Y]=np.meshgrid(x,y)
##initalise velocity
u=np.zeros((Ny,Nx),dtype=float)
v=np.zeros((Ny,Nx),dtype=float)
##initialise density
rho=np.ones((Ny,Nx),dtype=float)
##initalise Temperature
T=np.zeros((Ny,Nx),dtype=float)
###To compute kinematic viscoisty using Rayleigh number and prandtl number
csq=1/3
Pr=0.71
Ra=1e5
gy=-9.81
# beta=1.01937e-4
Th=1
Tc=0
Ma=0.1
# nu=np.sqrt((Pr/Ra)*beta*(Th-Tc)*np.abs(gy)*Ny**3)
nu=np.sqrt(((Ma**2)*(Ny**2)*Pr*csq)/(Ra))
# nu=0.01
# u_ref=np.sqrt((Ra*nu**2)/(Ny**2*Pr))
# Ma_ref=np.sqrt(3)*u_ref
# print(Ma_ref)
tau_nu=3*nu +0.5
omega=1/(tau_nu)
alpha=nu/Pr
tau_alpha=3*alpha+0.5
omega_s=1/(tau_alpha)
beta=(Ra*nu*alpha)/(np.abs(gy)*Ny**3*(Th-Tc))
```

```python
print(omega,omega_s)
##Boundary conditions on the channel
Tw=Th
Te=Tc
##Assigning boundary condition
T[1:Ny-1,0]=Tw
T[1:Ny-1,Nx-1]=Te
##Initialise local particle distribution function
f0=np.zeros((Ny,Nx),dtype=float)
f1=np.zeros((Ny,Nx),dtype=float)
f2=np.zeros((Ny,Nx),dtype=float)
f3=np.zeros((Ny,Nx),dtype=float)
f4=np.zeros((Ny,Nx),dtype=float)
f5=np.zeros((Ny,Nx),dtype=float)
f6=np.zeros((Ny,Nx),dtype=float)
f7=np.zeros((Ny,Nx),dtype=float)
f8=np.zeros((Ny,Nx),dtype=float)
##post collision local particle distribution function
f0c=np.zeros((Ny,Nx),dtype=float)
f1c=np.zeros((Ny,Nx),dtype=float)
f2c=np.zeros((Ny,Nx),dtype=float)
f3c=np.zeros((Ny,Nx),dtype=float)
f4c=np.zeros((Ny,Nx),dtype=float)
f5c=np.zeros((Ny,Nx),dtype=float)
f6c=np.zeros((Ny,Nx),dtype=float)
f7c=np.zeros((Ny,Nx),dtype=float)
f8c=np.zeros((Ny,Nx),dtype=float)
##Weights od digital particles
w0=4/9
w1=1/9
w2=1/9
w3=1/9
w4=1/9
w5=1/36
w6=1/36
w7=1/36
w8=1/36
##Initilaise equilibrium distribution function
f0eq=np.zeros((Ny,Nx),dtype=float)
f1eq=np.zeros((Ny,Nx),dtype=float)
f2eq=np.zeros((Ny,Nx),dtype=float)
f3eq=np.zeros((Ny,Nx),dtype=float)
f4eq=np.zeros((Ny,Nx),dtype=float)
f5eq=np.zeros((Ny,Nx),dtype=float)
f6eq=np.zeros((Ny,Nx),dtype=float)
f7eq=np.zeros((Ny,Nx),dtype=float)
f8eq=np.zeros((Ny,Nx),dtype=float)
```

```python
##compute equilibrium distribution function
f0eq=w0*rho*(1-0.5*((u**2+v**2)/csq))
f1eq=w1*rho*(1+u/csq+0.5*(u**2/csq**2)-0.5*((u**2+v**2)/csq))
f2eq=w2*rho*(1-u/csq+0.5*(u**2/csq**2)-0.5*((u**2+v**2)/csq))
f3eq=w3*rho*(1-v/csq+0.5*(v**2/csq**2)-0.5*((u**2+v**2)/csq))
f4eq=w4*rho*(1+v/csq+0.5*(v**2/csq**2)-0.5*((u**2+v**2)/csq))
f5eq=w5*rho*(1+(u-v)/csq+0.5*((u-v)**2/csq**2)-0.5*((u**2+v**2)/csq))
f6eq=w6*rho*(1+(v-u)/csq+0.5*((v-u)**2/csq**2)-0.5*((u**2+v**2)/csq))
f7eq=w7*rho*(1-(u+v)/csq+0.5*((u+v)**2/csq**2)-0.5*((u**2+v**2)/csq))
f8eq=w8*rho*(1+(u+v)/csq+0.5*((u+v)**2/csq**2)-0.5*((u**2+v**2)/csq))
##Initialisation of equilibrium functions
f0=f0eq
f1=f1eq
f2=f2eq
f3=f3eq
f4=f4eq
f5=f5eq
f6=f6eq
f7=f7eq
f8=f8eq
##Source term
gy=-9.81
S0=np.zeros((Ny,Nx),dtype=float)
S1=np.zeros((Ny,Nx),dtype=float)
S2=np.zeros((Ny,Nx),dtype=float)
S3=np.zeros((Ny,Nx),dtype=float)
S4=np.zeros((Ny,Nx),dtype=float)
S5=np.zeros((Ny,Nx),dtype=float)
S6=np.zeros((Ny,Nx),dtype=float)
S7=np.zeros((Ny,Nx),dtype=float)
S8=np.zeros((Ny,Nx),dtype=float)
##Computing Buoyancy force using Boussinesq approximation
T_m=Tc
for i in np.arange(1,Ny-1):
    for j in np.arange(1,Nx-1):
        S3[i,j]=3*w3*rho[i,j]*beta*(T[i,j]-T_m)*(gy*(-1))
        S4[i,j]=3*w4*rho[i,j]*beta*(T[i,j]-T_m)*(gy*(1))
        S5[i,j]=3*w5*rho[i,j]*beta*(T[i,j]-T_m)*(gy*(-1))
        S6[i,j]=3*w6*rho[i,j]*beta*(T[i,j]-T_m)*(gy*(1))
        S7[i,j]=3*w7*rho[i,j]*beta*(T[i,j]-T_m)*(gy*(-1))
        S8[i,j]=3*w8*rho[i,j]*beta*(T[i,j]-T_m)*(gy*(1))
###collision at each lattice node
for i in np.arange(1,Ny-1):
    for j in np.arange(1,Nx-1):
        f0c[i,j]=f0[i,j]*(1-omega)+omega*f0eq[i,j]+S0[i,j]
        f1c[i,j]=f1[i,j]*(1-omega)+omega*f1eq[i,j]+S1[i,j]
        f2c[i,j]=f2[i,j]*(1-omega)+omega*f2eq[i,j]+S2[i,j]
```

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        f3c[i,j]=f3[i,j]*(1-omega)+omega*f3eq[i,j]+S3[i,j]
        f4c[i,j]=f4[i,j]*(1-omega)+omega*f4eq[i,j]+S4[i,j]
        f5c[i,j]=f5[i,j]*(1-omega)+omega*f5eq[i,j]+S5[i,j]
        f6c[i,j]=f6[i,j]*(1-omega)+omega*f6eq[i,j]+S6[i,j]
        f7c[i,j]=f7[i,j]*(1-omega)+omega*f7eq[i,j]+S7[i,j]
        f8c[i,j]=f8[i,j]*(1-omega)+omega*f8eq[i,j]+S8[i,j]

##North boundary
f0c[0,:]=f0[0,:]
f1c[0,:]=f1[0,:]
f2c[0,:]=f2[0,:]
f3c[0,:]=f3[0,:]
f4c[0,:]=f4[0,:]
f5c[0,:]=f5[0,:]
f6c[0,:]=f6[0,:]
f7c[0,:]=f7[0,:]
f8c[0,:]=f8[0,:]
##South boundary
i=Ny-1
f0c[i,:]=f0[i,:]
f1c[i,:]=f1[i,:]
f2c[i,:]=f2[i,:]
f3c[i,:]=f3[i,:]
f4c[i,:]=f4[i,:]
f5c[i,:]=f5[i,:]
f6c[i,:]=f6[i,:]
f7c[i,:]=f7[i,:]
f8c[i,:]=f8[i,:]
# ##West boundary
f0c[1:Ny-1,0]=f0[1:Ny-1,0]
f1c[1:Ny-1,0]=f1[1:Ny-1,0]
f2c[1:Ny-1,0]=f2[1:Ny-1,0]
f3c[1:Ny-1,0]=f3[1:Ny-1,0]
f4c[1:Ny-1,0]=f4[1:Ny-1,0]
f5c[1:Ny-1,0]=f5[1:Ny-1,0]
f6c[1:Ny-1,0]=f6[1:Ny-1,0]
f7c[1:Ny-1,0]=f7[1:Ny-1,0]
f8c[1:Ny-1,0]=f8[1:Ny-1,0]
# ##East boundary
f0c[1:Ny-1,Nx-1]=f0[1:Ny-1,Nx-1]
f1c[1:Ny-1,Nx-1]=f1[1:Ny-1,Nx-1]
f2c[1:Ny-1,Nx-1]=f2[1:Ny-1,Nx-1]
f3c[1:Ny-1,Nx-1]=f3[1:Ny-1,Nx-1]
f4c[1:Ny-1,Nx-1]=f4[1:Ny-1,Nx-1]
f5c[1:Ny-1,Nx-1]=f5[1:Ny-1,Nx-1]
f6c[1:Ny-1,Nx-1]=f6[1:Ny-1,Nx-1]
f7c[1:Ny-1,Nx-1]=f7[1:Ny-1,Nx-1]
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```python
f8c[1:Ny-1,Nx-1]=f8[1:Ny-1,Nx-1]
##Streaming of digital particle
##Streaming of digital particle 0 at rest
f0=f0c
##Streaming of digital particle 1
for i in np.arange(0,Ny):
    for j in np.arange(0,Nx-1):
        f1[i,j+1]=f1c[i,j]
##Streaming of digital particle 2
for i in np.arange(0,Ny):
    for j in np.arange(0,Nx-1):
        f2[i,j]=f2c[i,j+1]
##Streaming of digital particle 3
for j in np.arange(0,Nx):
    for i in np.arange(0,Ny-1):
         f3[i,j]=f3c[i+1,j]

##Streaming of digital particle 4
for j in np.arange(0,Nx):
    for i in np.arange(0,Ny-1):
        f4[i+1,j]=f4c[i,j]
##Streaming of digital particle 5
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        f5[i,j+1]=f5c[i+1,j]
##Streaming of digital particle 6
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        f6[i+1,j]=f6c[i,j+1]
##Streaming of digital particle 7
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        f7[i,j]=f7c[i+1,j+1]
##Streaming of digital particle 8
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        f8[i+1,j+1]=f8c[i,j]

##West wall
j=0
for i in np.arange(1,Ny-1):
    f1[i,j]=f2[i,j]
    f5[i,j]=f6[i,j]
    f8[i,j]=f7[i,j]



##East wall
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```
j=Nx-1
for i in np.arange(1,Ny-1):
    f2[i,j]=f2[i,j-1]
    f6[i,j]=f6[i,j-1]
    f7[i,j]=f7[i,j-1]

##bottom wall is stationary
i=Ny-1
for j in np.arange(1,Nx-1):
    f3[i,j]=f4[i,j]
    f5[i,j]=f6[i,j]
    f7[i,j]=f8[i,j]

j=0
i=Ny-1
f1[i,j]=f2[i,j]
f3[i,j]=f4[i,j]
f5[i,j]=f6[i,j]
f8[i,j]=0.5*(rho[i,j]-(f0[i,j]+f1[i,j]+f2[i,j]+f3[i,j]+f4[i,j]+f5[i,j]+f6[i,j]))
f7[i,j]=f8[i,j]

i=Ny-1
j=Nx-1
f2[i,j]=f1[i,j]
f3[i,j]=f4[i,j]
f7[i,j]=f8[i,j]
f5[i,j]=0.5*(rho[i,j]-(f0[i,j]+f1[i,j]+f2[i,j]+f3[i,j]+f4[i,j]+f7[i,j]+f8[i,j]))
f6[i,j]=f5[i,j]

##top wall is stationary
f1[0,0]=f2[0,0]
f4[0,0]=f3[0,0]
f8[0,0]=f7[0,0]
f6[0,0]=0.5*(rho[0,0]-(f0[0,0]+f1[0,0]+f2[0,0]+f3[0,0]+f4[0,0]+f7[0,0]+f8[0,0]))
f5[0,0]=f6[0,0]


i=0
for j in np.arange(1,Nx-1):
    f4[i,j]=f3[i,j]
    f6[i,j]=f5[i,j]
    f8[i,j]=f7[i,j]

i=0
j=Nx-1
f2[0,j]=f1[0,j]
f4[0,j]=f3[0,j]
```

```
f6[0,j]=f5[0,j]
f8[0,j]=0.5*(rho[0,j]-(f0[0,j]+f1[0,j]+f2[0,j]+f3[0,j]+f4[0,j]+f5[0,j]+f6[0,j]))
f7[0,j]=f8[0,j]
#f0[0,j]=rho[0,j]-(f1[0,j]+f2[0,j]+f3[0,j]+f4[0,j]+f5[0,j]+f6[0,j]+f7[0,j]+f8[0,j])



##compute macroscopic property
for i in np.arange(1,Ny-1):
    for j in np.arange(1,Nx-1):
        ␣
 ↪rho[i,j]=f0[i,j]+f1[i,j]+f2[i,j]+f3[i,j]+f4[i,j]+f5[i,j]+f6[i,j]+f7[i,j]+f8[i,j]
        u[i,j]=(1/rho[i,j])*(f1[i,j]+f5[i,j]+f8[i,j]-(f2[i,j]+f6[i,j]+f7[i,j]))
        v[i,j]=(1/rho[i,j])*(f4[i,j]+f6[i,j]+f8[i,j]-(f3[i,j]+f5[i,j]+f7[i,j]))
```

```
1.895047875555446 1.8552819758410928
```

[6]:
```
##Initialise local particle distribution function
g0=np.zeros((Ny,Nx),dtype=float)
g1=np.zeros((Ny,Nx),dtype=float)
g2=np.zeros((Ny,Nx),dtype=float)
g3=np.zeros((Ny,Nx),dtype=float)
g4=np.zeros((Ny,Nx),dtype=float)
g5=np.zeros((Ny,Nx),dtype=float)
g6=np.zeros((Ny,Nx),dtype=float)
g7=np.zeros((Ny,Nx),dtype=float)
g8=np.zeros((Ny,Nx),dtype=float)
##post collision local particle distribution function
g0c=np.zeros((Ny,Nx),dtype=float)
g1c=np.zeros((Ny,Nx),dtype=float)
g2c=np.zeros((Ny,Nx),dtype=float)
g3c=np.zeros((Ny,Nx),dtype=float)
g4c=np.zeros((Ny,Nx),dtype=float)
g5c=np.zeros((Ny,Nx),dtype=float)
g6c=np.zeros((Ny,Nx),dtype=float)
g7c=np.zeros((Ny,Nx),dtype=float)
g8c=np.zeros((Ny,Nx),dtype=float)
##Weights od digital particles
w0=4/9
w1=1/9
w2=1/9
w3=1/9
w4=1/9
w5=1/36
w6=1/36
w7=1/36
w8=1/36
```

```python
##To compute equilibrium distribution function
g0eq=np.zeros((Ny,Nx),dtype=float)
g1eq=np.zeros((Ny,Nx),dtype=float)
g2eq=np.zeros((Ny,Nx),dtype=float)
g3eq=np.zeros((Ny,Nx),dtype=float)
g4eq=np.zeros((Ny,Nx),dtype=float)
g5eq=np.zeros((Ny,Nx),dtype=float)
g6eq=np.zeros((Ny,Nx),dtype=float)
g7eq=np.zeros((Ny,Nx),dtype=float)
g8eq=np.zeros((Ny,Nx),dtype=float)
##Compute equilibrium df
g0eq=w0*T
g1eq=w1*T*(1+u/csq)
g2eq=w2*T*(1-u/csq)
g3eq=w3*T*(1-v/csq)
g4eq=w4*T*(1+v/csq)
g5eq=w5*T*(1+((u-v)/csq))
g6eq=w6*T*(1+((-u+v)/csq))
g7eq=w7*T*(1-((v+u)/csq))
g8eq=w8*T*(1+((u+v)/csq))
##Initialisation of equilibrium functions
g0=g0eq
g1=g1eq
g2=g2eq
g3=g3eq
g4=g4eq
g5=g5eq
g6=g6eq
g7=g7eq
g8=g8eq
###collision at each lattice node
for i in np.arange(1,Ny-1):
    for j in np.arange(1,Nx-1):
        g0c[i,j]=g0[i,j]*(1-omega_s)+omega_s*g0eq[i,j]
        g1c[i,j]=g1[i,j]*(1-omega_s)+omega_s*g1eq[i,j]
        g2c[i,j]=g2[i,j]*(1-omega_s)+omega_s*g2eq[i,j]
        g3c[i,j]=g3[i,j]*(1-omega_s)+omega_s*g3eq[i,j]
        g4c[i,j]=g4[i,j]*(1-omega_s)+omega_s*g4eq[i,j]
        g5c[i,j]=g5[i,j]*(1-omega_s)+omega_s*g5eq[i,j]
        g6c[i,j]=g6[i,j]*(1-omega_s)+omega_s*g6eq[i,j]
        g7c[i,j]=g7[i,j]*(1-omega_s)+omega_s*g7eq[i,j]
        g8c[i,j]=g8[i,j]*(1-omega_s)+omega_s*g8eq[i,j]

##North boundary
g0c[0,:]=g0[0,:]
g1c[0,:]=g1[0,:]
g2c[0,:]=g2[0,:]
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```python
g3c[0,:]=g3[0,:]
g4c[0,:]=g4[0,:]
g5c[0,:]=g5[0,:]
g6c[0,:]=g6[0,:]
g7c[0,:]=g7[0,:]
g8c[0,:]=g8[0,:]
##South boundary
i=Ny-1
g0c[i,:]=g0[i,:]
g1c[i,:]=g1[i,:]
g2c[i,:]=g2[i,:]
g3c[i,:]=g3[i,:]
g4c[i,:]=g4[i,:]
g5c[i,:]=g5[i,:]
g6c[i,:]=g6[i,:]
g7c[i,:]=g7[i,:]
g8c[i,:]=g8[i,:]
###West boundary
g0c[1:Ny-1,0]=g0[1:Ny-1,0]
g1c[1:Ny-1,0]=g1[1:Ny-1,0]
g2c[1:Ny-1,0]=g2[1:Ny-1,0]
g3c[1:Ny-1,0]=g3[1:Ny-1,0]
g4c[1:Ny-1,0]=g4[1:Ny-1,0]
g5c[1:Ny-1,0]=g5[1:Ny-1,0]
g6c[1:Ny-1,0]=g6[1:Ny-1,0]
g7c[1:Ny-1,0]=g7[1:Ny-1,0]
g8c[1:Ny-1,0]=g8[1:Ny-1,0]
# ##East boundary
g0c[1:Ny-1,Nx-1]=g0[1:Ny-1,Nx-1]
g1c[1:Ny-1,Nx-1]=g1[1:Ny-1,Nx-1]
g2c[1:Ny-1,Nx-1]=g2[1:Ny-1,Nx-1]
g3c[1:Ny-1,Nx-1]=g3[1:Ny-1,Nx-1]
g4c[1:Ny-1,Nx-1]=g4[1:Ny-1,Nx-1]
g5c[1:Ny-1,Nx-1]=g5[1:Ny-1,Nx-1]
g6c[1:Ny-1,Nx-1]=g6[1:Ny-1,Nx-1]
g7c[1:Ny-1,Nx-1]=g7[1:Ny-1,Nx-1]
g8c[1:Ny-1,Nx-1]=g8[1:Ny-1,Nx-1]


##Streaming of digital particle
##Streaming of digital particle 0 at rest
g0=g0c
##Streaming of digital particle 1
for i in np.arange(0,Ny):
    for j in np.arange(0,Nx-1):
        g1[i,j+1]=g1c[i,j]
##Streaming of digital particle 2
```

```python
for i in np.arange(0,Ny):
    for j in np.arange(0,Nx-1):
         g2[i,j]=g2c[i,j+1]
##Streaming of digital particle 3
##West boundary
for j in np.arange(0,Nx):
    for i in np.arange(0,Ny-1):
        g3[i,j]=g3c[i+1,j]

##Streaming of digital particle 4
##Westboundary
for j in np.arange(0,Nx):
    for i in np.arange(0,Ny-1):
        g4[i+1,j]=g4c[i,j]

##Streaming of digital particle 5
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        g5[i,j+1]=g5c[i+1,j]

##Streaming of digital particle 6
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        g6[i+1,j]=g6c[i,j+1]

##Streaming of digital particle 7
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        g7[i,j]=g7c[i+1,j+1]

##Streaming of digital particle 8
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        g8[i+1,j+1]=g8c[i,j]

##Applying boundary condition and obtaining unknowns
##North boundary
##left corner lattice node
##unknown df are g1,g4,g5,g6,g8
g1[0,0]=g2[0,0]
g4[0,0]=g3[0,0]
g8[0,0]=g7[0,0]
g6[0,0]=0.5*(T[0,0]-(g0[0,0]+g1[0,0]+g2[0,0]+g3[0,0]+g4[0,0]+g7[0,0]+g8[0,0]))
g5[0,0]=g6[0,0]
##interior lattice node
##unknown df are g4,g6,g8
i=0
```

```python
for j in np.arange(1,Nx-1):
    g4[i,j]=g3[i,j]
    g6[i,j]=g5[i,j]
    g8[i,j]=g7[i,j]

##right corner lattice node
##unknown df are g2,g4,g6,g7,g8
i=0
j=Nx-1
g2[i,j]=g1[i,j]
g4[i,j]=g3[i,j]
g6[i,j]=g5[i,j]
g8[i,j]=0.5*(T[i,j]-(g0[i,j]+g1[i,j]+g2[i,j]+g3[i,j]+g4[i,j]+g5[i,j]+g6[i,j]))
g7[i,j]=g8[i,j]


##South bondary/bottom boundary
##left corner lattice node
##unknown df are g1,g3,g5,g7,,g8
i=Ny-1
j=0
g1[i,j]=g2[i,j]
g3[i,j]=g4[i,j]
g5[i,j]=g6[i,j]
g8[i,j]=0.5*(T[i,j]-(g0[i,j]+g1[i,j]+g2[i,j]+g3[i,j]+g4[i,j]+g5[i,j]+g6[i,j]))
g7[i,j]=g8[i,j]

##Interior lattice nodes
##unknown df are g3,g5,g7
i=Ny-1
for j in np.arange(1,Nx-1):
    g3[i,j]=g4[i,j]
    g5[i,j]=g6[i,j]
    g7[i,j]=g8[i,j]

##right corner lattice nodes
##unknown df are g2,g3,g5,g6,g7
i=Ny-1
j=Nx-1
g2[i,j]=g1[i,j]
g3[i,j]=g4[i,j]
g7[i,j]=g8[i,j]
g6[i,j]=0.5*(T[i,j]-(g0[i,j]+g1[i,j]+g2[i,j]+g3[i,j]+g4[i,j]+g7[i,j]+g8[i,j]))
g5[i,j]=g6[i,j]


##West boundary
```

```
j=0
for i in np.arange(1,Ny-1):
    g1[i,j]=(w1+w2)*Tw-g2[i,j]
    g5[i,j]=(w5+w6)*Tw-g6[i,j]
    g8[i,j]=(w7+w8)*Tw-g7[i,j]
    #g8[i,j]=Tw*(1-(w1+w2+w5+w6))-g0[i,j]-g3[i,j]-g4[i,j]-g7[i,j]



##East boundary
j=Nx-1
for i in np.arange(1,Ny-1):
    if(u[i,j]>0):
        g2[i,j]=g2[i,j-1]
        g6[i,j]=g6[i,j-1]
        g7[i,j]=g7[i,j-1]
    if(u[i,j]<0):
        g2[i,j]=-g1[i,j]
        g6[i,j]=-g5[i,j]
        g7[i,j]=-g8[i,j]

##compute macroscopic property
for i in np.arange(1,Ny-1):
    for j in np.arange(1,Nx-1):
        ␣
 ↪T[i,j]=g0[i,j]+g1[i,j]+g2[i,j]+g3[i,j]+g4[i,j]+g5[i,j]+g6[i,j]+g7[i,j]+g8[i,j]
```

[7]:

```
iter=20000
while(iter>=1):
    ##compute equilibrium distribution function
    f0eq=w0*rho*(1-0.5*((u**2+v**2)/csq))
    f1eq=w1*rho*(1+u/csq+0.5*(u**2/csq**2)-0.5*((u**2+v**2)/csq))
    f2eq=w2*rho*(1-u/csq+0.5*(u**2/csq**2)-0.5*((u**2+v**2)/csq))
    f3eq=w3*rho*(1-v/csq+0.5*(v**2/csq**2)-0.5*((u**2+v**2)/csq))
    f4eq=w4*rho*(1+v/csq+0.5*(v**2/csq**2)-0.5*((u**2+v**2)/csq))
    f5eq=w5*rho*(1+(u-v)/csq+0.5*((u-v)**2/csq**2)-0.5*((u**2+v**2)/csq))
    f6eq=w6*rho*(1+(v-u)/csq+0.5*((v-u)**2/csq**2)-0.5*((u**2+v**2)/csq))
    f7eq=w7*rho*(1-(u+v)/csq+0.5*((u+v)**2/csq**2)-0.5*((u**2+v**2)/csq))
    f8eq=w8*rho*(1+(u+v)/csq+0.5*((u+v)**2/csq**2)-0.5*((u**2+v**2)/csq))
    ##Computing Buoyancy force using Boussinesq approximation
#     T_m=(Th+Tc)/2
    T_m=Tc
    for i in np.arange(1,Ny-1):
        for j in np.arange(1,Nx-1):
            S3[i,j]=3*w3*rho[i,j]*beta*(T[i,j]-T_m)*(gy*(-1))
            S4[i,j]=3*w4*rho[i,j]*beta*(T[i,j]-T_m)*(gy*(1))
            S5[i,j]=3*w5*rho[i,j]*beta*(T[i,j]-T_m)*(gy*(-1))
            S6[i,j]=3*w6*rho[i,j]*beta*(T[i,j]-T_m)*(gy*(1))
```

```python
            S7[i,j]=3*w7*rho[i,j]*beta*(T[i,j]-T_m)*(gy*(-1))
            S8[i,j]=3*w8*rho[i,j]*beta*(T[i,j]-T_m)*(gy*(1))
    ###collision at each lattice node
    for i in np.arange(1,Ny-1):
        for j in np.arange(1,Nx-1):
            f0c[i,j]=f0[i,j]*(1-omega)+omega*f0eq[i,j]+S0[i,j]
            f1c[i,j]=f1[i,j]*(1-omega)+omega*f1eq[i,j]+S1[i,j]
            f2c[i,j]=f2[i,j]*(1-omega)+omega*f2eq[i,j]+S2[i,j]
            f3c[i,j]=f3[i,j]*(1-omega)+omega*f3eq[i,j]+S3[i,j]
            f4c[i,j]=f4[i,j]*(1-omega)+omega*f4eq[i,j]+S4[i,j]
            f5c[i,j]=f5[i,j]*(1-omega)+omega*f5eq[i,j]+S5[i,j]
            f6c[i,j]=f6[i,j]*(1-omega)+omega*f6eq[i,j]+S6[i,j]
            f7c[i,j]=f7[i,j]*(1-omega)+omega*f7eq[i,j]+S7[i,j]
            f8c[i,j]=f8[i,j]*(1-omega)+omega*f8eq[i,j]+S8[i,j]

    ##North boundary
    f0c[0,:]=f0[0,:]
    f1c[0,:]=f1[0,:]
    f2c[0,:]=f2[0,:]
    f3c[0,:]=f3[0,:]
    f4c[0,:]=f4[0,:]
    f5c[0,:]=f5[0,:]
    f6c[0,:]=f6[0,:]
    f7c[0,:]=f7[0,:]
    f8c[0,:]=f8[0,:]
    ##South boundary
    i=Ny-1
    f0c[i,:]=f0[i,:]
    f1c[i,:]=f1[i,:]
    f2c[i,:]=f2[i,:]
    f3c[i,:]=f3[i,:]
    f4c[i,:]=f4[i,:]
    f5c[i,:]=f5[i,:]
    f6c[i,:]=f6[i,:]
    f7c[i,:]=f7[i,:]
    f8c[i,:]=f8[i,:]
    # ##West boundary
    f0c[1:Ny-1,0]=f0[1:Ny-1,0]
    f1c[1:Ny-1,0]=f1[1:Ny-1,0]
    f2c[1:Ny-1,0]=f2[1:Ny-1,0]
    f3c[1:Ny-1,0]=f3[1:Ny-1,0]
    f4c[1:Ny-1,0]=f4[1:Ny-1,0]
    f5c[1:Ny-1,0]=f5[1:Ny-1,0]
    f6c[1:Ny-1,0]=f6[1:Ny-1,0]
    f7c[1:Ny-1,0]=f7[1:Ny-1,0]
    f8c[1:Ny-1,0]=f8[1:Ny-1,0]
    # ##East boundary
```

```
f0c[1:Ny-1,Nx-1]=f0[1:Ny-1,Nx-1]
f1c[1:Ny-1,Nx-1]=f1[1:Ny-1,Nx-1]
f2c[1:Ny-1,Nx-1]=f2[1:Ny-1,Nx-1]
f3c[1:Ny-1,Nx-1]=f3[1:Ny-1,Nx-1]
f4c[1:Ny-1,Nx-1]=f4[1:Ny-1,Nx-1]
f5c[1:Ny-1,Nx-1]=f5[1:Ny-1,Nx-1]
f6c[1:Ny-1,Nx-1]=f6[1:Ny-1,Nx-1]
f7c[1:Ny-1,Nx-1]=f7[1:Ny-1,Nx-1]
f8c[1:Ny-1,Nx-1]=f8[1:Ny-1,Nx-1]
##Streaming of digital particle
##Streaming of digital particle 0 at rest
f0=f0c
##Streaming of digital particle 1
for i in np.arange(0,Ny):
    for j in np.arange(0,Nx-1):
        f1[i,j+1]=f1c[i,j]
##Streaming of digital particle 2
for i in np.arange(0,Ny):
    for j in np.arange(0,Nx-1):
        f2[i,j]=f2c[i,j+1]
##Streaming of digital particle 3
for j in np.arange(0,Nx):
    for i in np.arange(0,Ny-1):
         f3[i,j]=f3c[i+1,j]

##Streaming of digital particle 4
for j in np.arange(0,Nx):
    for i in np.arange(0,Ny-1):
        f4[i+1,j]=f4c[i,j]
##Streaming of digital particle 5
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        f5[i,j+1]=f5c[i+1,j]
##Streaming of digital particle 6
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        f6[i+1,j]=f6c[i,j+1]
##Streaming of digital particle 7
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        f7[i,j]=f7c[i+1,j+1]
##Streaming of digital particle 8
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        f8[i+1,j+1]=f8c[i,j]
```

```
    ##West wall
    j=0
    for i in np.arange(1,Ny-1):
        f1[i,j]=f2[i,j]
        f5[i,j]=f6[i,j]
        f8[i,j]=f7[i,j]


    ##East wall
    j=Nx-1
    for i in np.arange(1,Ny-1):
        f2[i,j]=f2[i,j-1]
        f6[i,j]=f6[i,j-1]
        f7[i,j]=f7[i,j-1]

    ##bottom wall is stationary
    i=Ny-1
    for j in np.arange(1,Nx-1):
        f3[i,j]=f4[i,j]
        f5[i,j]=f6[i,j]
        f7[i,j]=f8[i,j]

    j=0
    i=Ny-1
    f1[i,j]=f2[i,j]
    f3[i,j]=f4[i,j]
    f5[i,j]=f6[i,j]
    f8[i,j]=0.
↪5*(rho[i,j]-(f0[i,j]+f1[i,j]+f2[i,j]+f3[i,j]+f4[i,j]+f5[i,j]+f6[i,j]))
    f7[i,j]=f8[i,j]

    i=Ny-1
    j=Nx-1
    f2[i,j]=f1[i,j]
    f3[i,j]=f4[i,j]
    f7[i,j]=f8[i,j]
    f5[i,j]=0.
↪5*(rho[i,j]-(f0[i,j]+f1[i,j]+f2[i,j]+f3[i,j]+f4[i,j]+f7[i,j]+f8[i,j]))
    f6[i,j]=f5[i,j]

    ##top wall is stationary
    f1[0,0]=f2[0,0]
    f4[0,0]=f3[0,0]
    f8[0,0]=f7[0,0]
    f6[0,0]=0.
↪5*(rho[0,0]-(f0[0,0]+f1[0,0]+f2[0,0]+f3[0,0]+f4[0,0]+f7[0,0]+f8[0,0]))
    f5[0,0]=f6[0,0]
```

```
    i=0
    for j in np.arange(1,Nx-1):
        f4[i,j]=f3[i,j]
        f6[i,j]=f5[i,j]
        f8[i,j]=f7[i,j]

    i=0
    j=Nx-1
    f2[0,j]=f1[0,j]
    f4[0,j]=f3[0,j]
    f6[0,j]=f5[0,j]
    f8[0,j]=0.
↪5*(rho[0,j]-(f0[0,j]+f1[0,j]+f2[0,j]+f3[0,j]+f4[0,j]+f5[0,j]+f6[0,j]))
    f7[0,j]=f8[0,j]
  ␣
↪#f0[0,j]=rho[0,j]-(f1[0,j]+f2[0,j]+f3[0,j]+f4[0,j]+f5[0,j]+f6[0,j]+f7[0,j]+f8[0,j])



    ##compute macroscopic property
    for i in np.arange(1,Ny-1):
        for j in np.arange(1,Nx-1):
          ␣
↪rho[i,j]=f0[i,j]+f1[i,j]+f2[i,j]+f3[i,j]+f4[i,j]+f5[i,j]+f6[i,j]+f7[i,j]+f8[i,j]
            u[i,j]=(1/
↪rho[i,j])*(f1[i,j]+f5[i,j]+f8[i,j]-(f2[i,j]+f6[i,j]+f7[i,j]))
            v[i,j]=(1/
↪rho[i,j])*(f4[i,j]+f6[i,j]+f8[i,j]-(f3[i,j]+f5[i,j]+f7[i,j]))




    ##Compute equilibrium df
    g0eq=w0*T
    g1eq=w1*T*(1+u/csq)
    g2eq=w2*T*(1-u/csq)
    g3eq=w3*T*(1-v/csq)
    g4eq=w4*T*(1+v/csq)
    g5eq=w5*T*(1+((u-v)/csq))
    g6eq=w6*T*(1+((-u+v)/csq))
    g7eq=w7*T*(1-((v+u)/csq))
    g8eq=w8*T*(1+((u+v)/csq))

    ###collision at each lattice node
    for i in np.arange(1,Ny-1):
```

```python
        for j in np.arange(1,Nx-1):
            g0c[i,j]=g0[i,j]*(1-omega_s)+omega_s*g0eq[i,j]
            g1c[i,j]=g1[i,j]*(1-omega_s)+omega_s*g1eq[i,j]
            g2c[i,j]=g2[i,j]*(1-omega_s)+omega_s*g2eq[i,j]
            g3c[i,j]=g3[i,j]*(1-omega_s)+omega_s*g3eq[i,j]
            g4c[i,j]=g4[i,j]*(1-omega_s)+omega_s*g4eq[i,j]
            g5c[i,j]=g5[i,j]*(1-omega_s)+omega_s*g5eq[i,j]
            g6c[i,j]=g6[i,j]*(1-omega_s)+omega_s*g6eq[i,j]
            g7c[i,j]=g7[i,j]*(1-omega_s)+omega_s*g7eq[i,j]
            g8c[i,j]=g8[i,j]*(1-omega_s)+omega_s*g8eq[i,j]

    ##North boundary
    g0c[0,:]=g0[0,:]
    g1c[0,:]=g1[0,:]
    g2c[0,:]=g2[0,:]
    g3c[0,:]=g3[0,:]
    g4c[0,:]=g4[0,:]
    g5c[0,:]=g5[0,:]
    g6c[0,:]=g6[0,:]
    g7c[0,:]=g7[0,:]
    g8c[0,:]=g8[0,:]
    ##South boundary
    i=Ny-1
    g0c[i,:]=g0[i,:]
    g1c[i,:]=g1[i,:]
    g2c[i,:]=g2[i,:]
    g3c[i,:]=g3[i,:]
    g4c[i,:]=g4[i,:]
    g5c[i,:]=g5[i,:]
    g6c[i,:]=g6[i,:]
    g7c[i,:]=g7[i,:]
    g8c[i,:]=g8[i,:]
    ###West boundary
    g0c[1:Ny-1,0]=g0[1:Ny-1,0]
    g1c[1:Ny-1,0]=g1[1:Ny-1,0]
    g2c[1:Ny-1,0]=g2[1:Ny-1,0]
    g3c[1:Ny-1,0]=g3[1:Ny-1,0]
    g4c[1:Ny-1,0]=g4[1:Ny-1,0]
    g5c[1:Ny-1,0]=g5[1:Ny-1,0]
    g6c[1:Ny-1,0]=g6[1:Ny-1,0]
    g7c[1:Ny-1,0]=g7[1:Ny-1,0]
    g8c[1:Ny-1,0]=g8[1:Ny-1,0]
    # ##East boundary
    g0c[1:Ny-1,Nx-1]=g0[1:Ny-1,Nx-1]
    g1c[1:Ny-1,Nx-1]=g1[1:Ny-1,Nx-1]
    g2c[1:Ny-1,Nx-1]=g2[1:Ny-1,Nx-1]
    g3c[1:Ny-1,Nx-1]=g3[1:Ny-1,Nx-1]
```

```
g4c[1:Ny-1,Nx-1]=g4[1:Ny-1,Nx-1]
g5c[1:Ny-1,Nx-1]=g5[1:Ny-1,Nx-1]
g6c[1:Ny-1,Nx-1]=g6[1:Ny-1,Nx-1]
g7c[1:Ny-1,Nx-1]=g7[1:Ny-1,Nx-1]
g8c[1:Ny-1,Nx-1]=g8[1:Ny-1,Nx-1]


##Streaming of digital particle
##Streaming of digital particle 0 at rest
g0=g0c
##Streaming of digital particle 1
for i in np.arange(0,Ny):
    for j in np.arange(0,Nx-1):
        g1[i,j+1]=g1c[i,j]
##Streaming of digital particle 2
for i in np.arange(0,Ny):
    for j in np.arange(0,Nx-1):
         g2[i,j]=g2c[i,j+1]
##Streaming of digital particle 3
##West boundary
for j in np.arange(0,Nx):
    for i in np.arange(0,Ny-1):
        g3[i,j]=g3c[i+1,j]

##Streaming of digital particle 4
##Westboundary
for j in np.arange(0,Nx):
    for i in np.arange(0,Ny-1):
        g4[i+1,j]=g4c[i,j]

##Streaming of digital particle 5
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        g5[i,j+1]=g5c[i+1,j]

##Streaming of digital particle 6
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        g6[i+1,j]=g6c[i,j+1]

##Streaming of digital particle 7
for i in np.arange(0,Ny-1):
    for j in np.arange(0,Nx-1):
        g7[i,j]=g7c[i+1,j+1]

##Streaming of digital particle 8
for i in np.arange(0,Ny-1):
```

```
        for j in np.arange(0,Nx-1):
            g8[i+1,j+1]=g8c[i,j]

    ##Applying boundary condition and obtaining unknowns
    ##North boundary
    ##left corner lattice node
    ##unknown df are g1,g4,g5,g6,g8
    g1[0,0]=g2[0,0]
    g4[0,0]=g3[0,0]
    g8[0,0]=g7[0,0]
    g6[0,0]=0.
↪5*(T[0,0]-(g0[0,0]+g1[0,0]+g2[0,0]+g3[0,0]+g4[0,0]+g7[0,0]+g8[0,0]))
    g5[0,0]=g6[0,0]
    ##interior lattice node
    ##unknown df are g4,g6,g8
    i=0
    for j in np.arange(1,Nx-1):
        g4[i,j]=g3[i,j]
        g6[i,j]=g5[i,j]
        g8[i,j]=g7[i,j]

    ##right corner lattice node
    ##unknown df are g2,g4,g6,g7,g8
    i=0
    j=Nx-1
    g2[i,j]=g1[i,j]
    g4[i,j]=g3[i,j]
    g6[i,j]=g5[i,j]
    g8[i,j]=0.
↪5*(T[i,j]-(g0[i,j]+g1[i,j]+g2[i,j]+g3[i,j]+g4[i,j]+g5[i,j]+g6[i,j]))
    g7[i,j]=g8[i,j]


    ##South bondary/bottom boundary
    ##left corner lattice node
    ##unknown df are g1,g3,g5,g7,,g8
    i=Ny-1
    j=0
    g1[i,j]=g2[i,j]
    g3[i,j]=g4[i,j]
    g5[i,j]=g6[i,j]
    g8[i,j]=0.
↪5*(T[i,j]-(g0[i,j]+g1[i,j]+g2[i,j]+g3[i,j]+g4[i,j]+g5[i,j]+g6[i,j]))
    g7[i,j]=g8[i,j]

    ##Interior lattice nodes
    ##unknown df are g3,g5,g7
```

```
    i=Ny-1
    for j in np.arange(1,Nx-1):
        g3[i,j]=g4[i,j]
        g5[i,j]=g6[i,j]
        g7[i,j]=g8[i,j]

    ##right corner lattice nodes
    ##unknown df are g2,g3,g5,g6,g7
    i=Ny-1
    j=Nx-1
    g2[i,j]=g1[i,j]
    g3[i,j]=g4[i,j]
    g7[i,j]=g8[i,j]
    g6[i,j]=0.
↪5*(T[i,j]-(g0[i,j]+g1[i,j]+g2[i,j]+g3[i,j]+g4[i,j]+g7[i,j]+g8[i,j]))
    g5[i,j]=g6[i,j]


    ##West boundary
    j=0
    for i in np.arange(1,Ny-1):
        g1[i,j]=(w1+w2)*Tw-g2[i,j]
        g5[i,j]=(w5+w6)*Tw-g6[i,j]
        g8[i,j]=(w7+w8)*Tw-g7[i,j]
        #g8[i,j]=Tw*(1-(w1+w2+w5+w6))-g0[i,j]-g3[i,j]-g4[i,j]-g7[i,j]


    ##East boundary
    j=Nx-1
    for i in np.arange(1,Ny-1):
        if(u[i,j]>0):
            g2[i,j]=g2[i,j-1]
            g6[i,j]=g6[i,j-1]
            g7[i,j]=g7[i,j-1]
        if(u[i,j]<0):
            g2[i,j]=-g1[i,j]
            g6[i,j]=-g5[i,j]
            g7[i,j]=-g8[i,j]

    ##compute macroscopic property
    for i in np.arange(1,Ny-1):
        for j in np.arange(1,Nx-1):
            ␣
↪T[i,j]=g0[i,j]+g1[i,j]+g2[i,j]+g3[i,j]+g4[i,j]+g5[i,j]+g6[i,j]+g7[i,j]+g8[i,j]


    print(iter)
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    iter=iter-1
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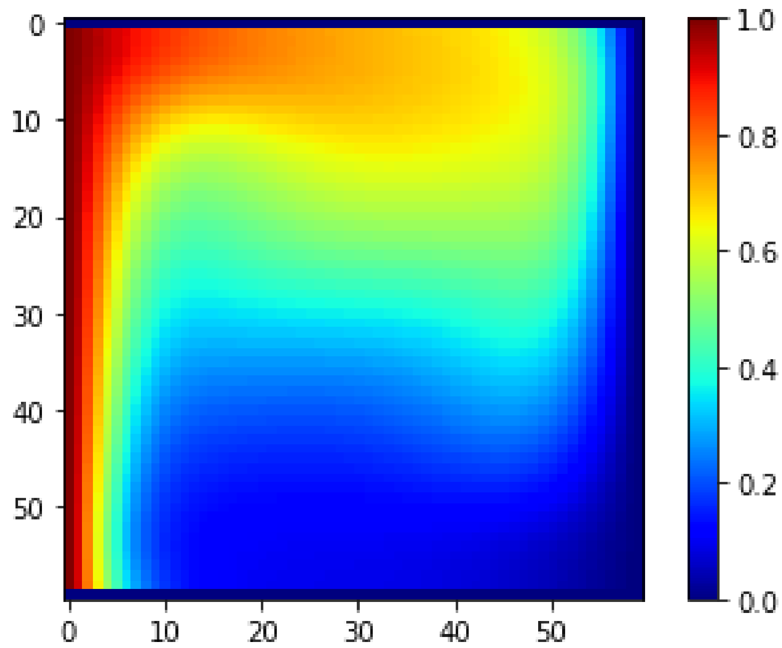
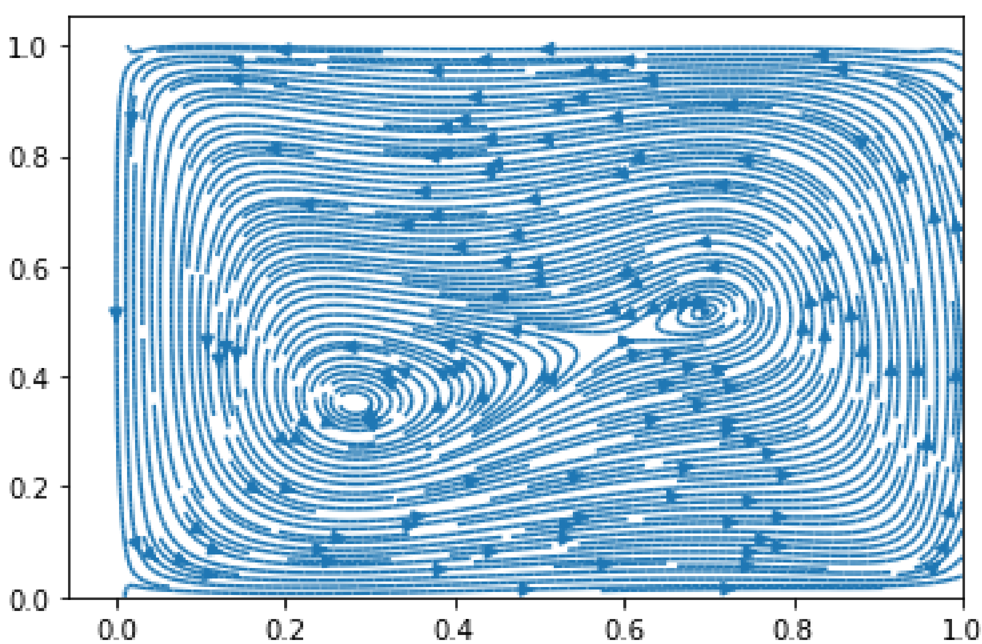
[8]:

```python
plt.imshow(T,cmap='jet')
plt.colorbar()
plt.show()
```




```
[9]: plt.streamplot(X,Y,u,v,density=3.0)
     plt.show()
```



[10]:
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plt.imshow(T,cmap='jet')
plt.colorbar()
plt.show()
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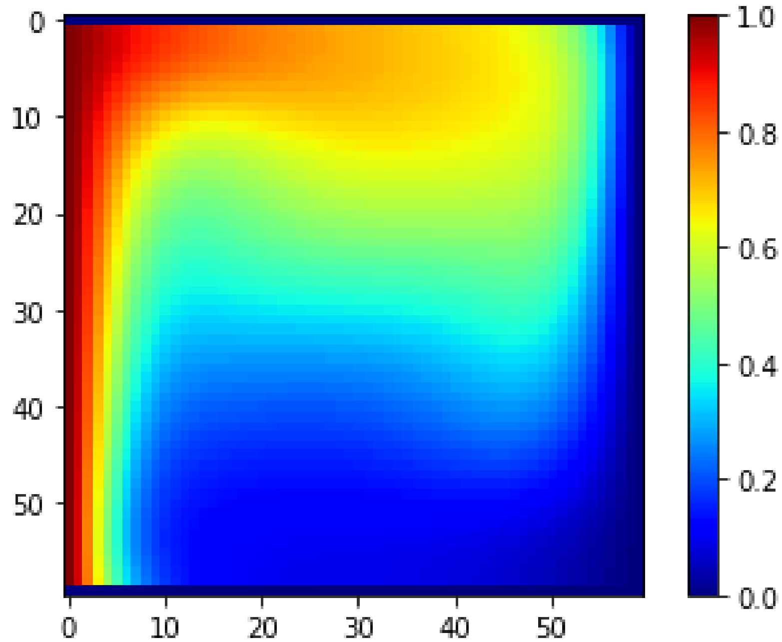

[11]:
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plt.streamplot(X,Y,u,v,density=3.0)
plt.show()
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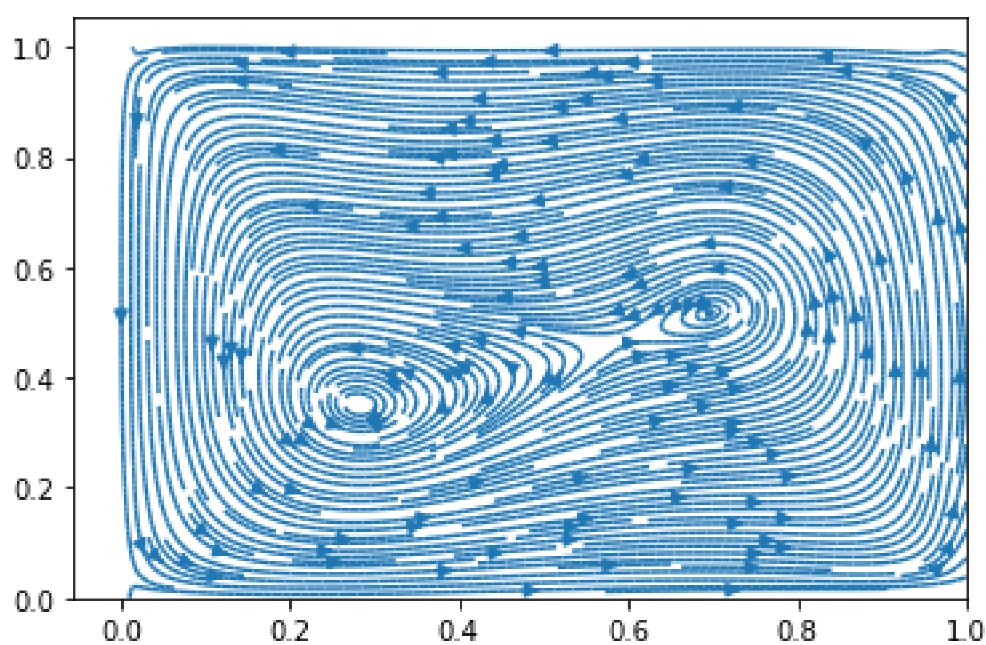

[12]:
```
np.max(T)
```

[12]: 1.0

[13]:
```
plt.imshow(np.sqrt(u**2+v**2),cmap='jet')
plt.colorbar()
plt.show()
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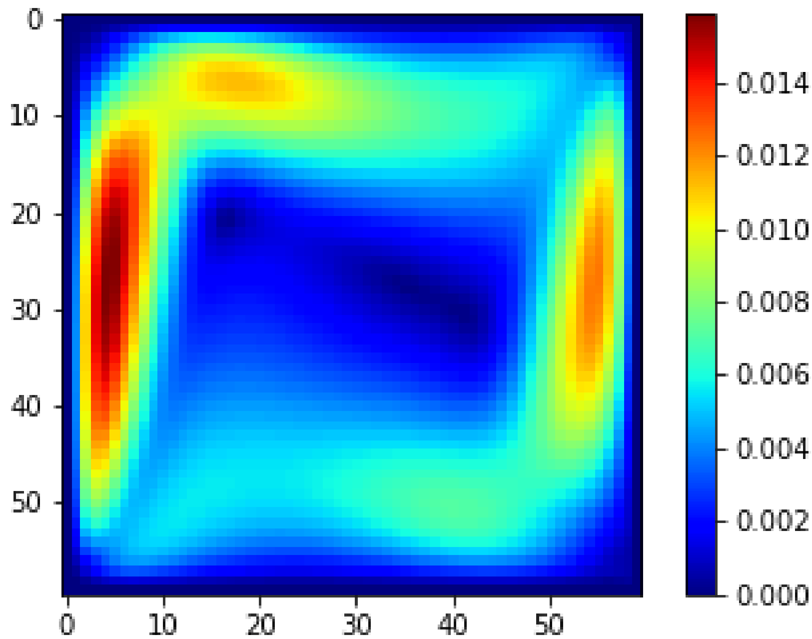

[18]:
```
plt.contour(np.sqrt(u**2+v**2),cmap='jet')
plt.colorbar()
plt.show()
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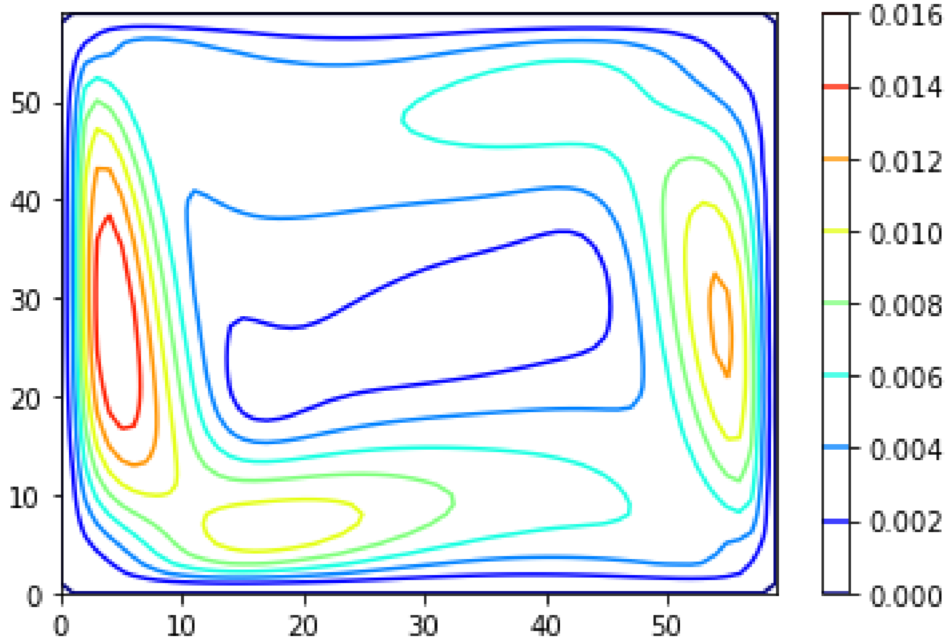
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