Numerical Solution of the Natural Convection Around a Horizontal Cylinder Subjected to Non-uniform Radiative Heat

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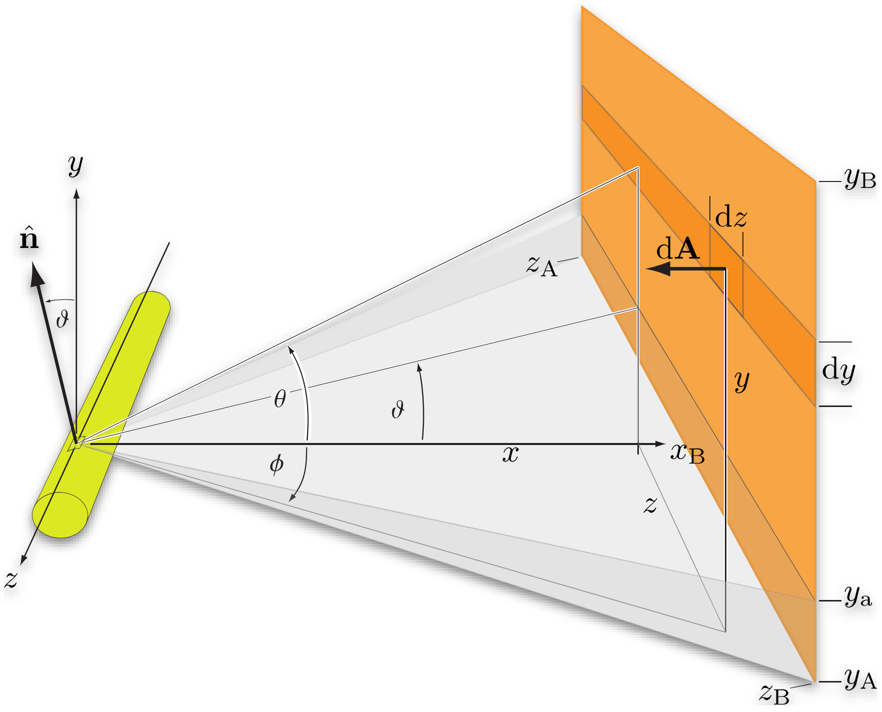
Wildfires

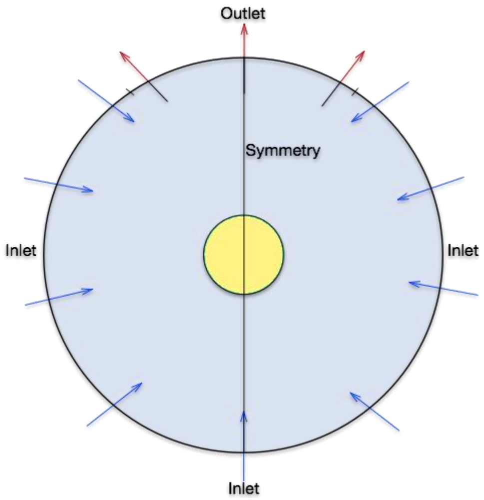
Controlled burns in Northumberland National Park, UK.



- Non-uniform heat from a hot panel.
- Panel represents flame-front.
- Flammability at around 300°C.
- Changes in heating rate and cylinder diameter explored.

$$
\begin{aligned}
\rho c_p \mathbf{u} \cdot \nabla T &= \nabla \cdot \lambda \nabla T \\
\rho \mathbf{u} \cdot \nabla \mathbf{u} + \nabla P &= \mathrm{Pr}\left(\nabla \cdot \boldsymbol{\tau} + \mathrm{Ra}\, \rho\, T\, \mathbf{j}\right) \\
\nabla \cdot \rho \mathbf{u} &= 0 \\
\rho &= \frac{1}{1 + A_T T} \\
\nabla \cdot \lambda_s \nabla \Theta &= 0.
\end{aligned}
$$

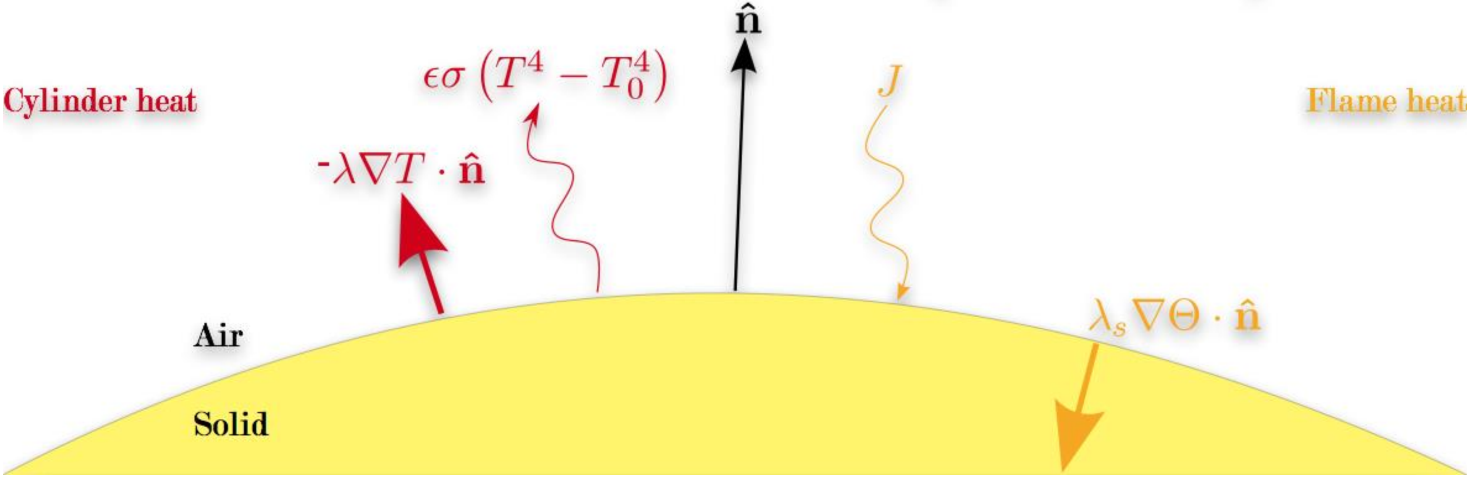
- Weakly compressible Navier-Stokes.
- Convection and conduction.
- Heat transfer by conduction.



- Inlet and outlet condition on exterior boundary.
- No-slip on cylinder.
- Continuity of temperature on solid-air interface.
- Heat flux boundary condition.

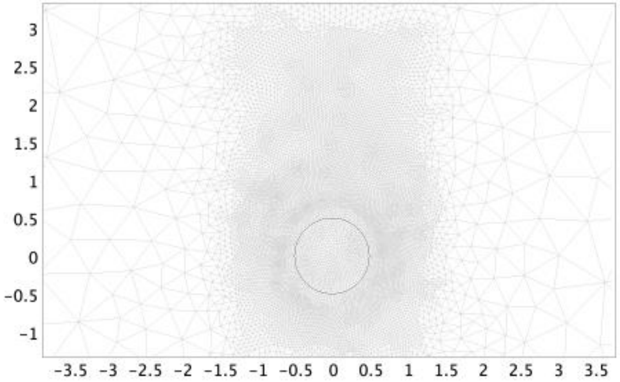
Heat flux boundary condition with non-uniform heating

$$B_\lambda \lambda_s \nabla\Theta \cdot \hat{\mathbf{n}} - \lambda \nabla T \cdot \hat{\mathbf{n}} = \psi(\vartheta) + D_R\left(1 - (1 + A_T T)^4\right)$$



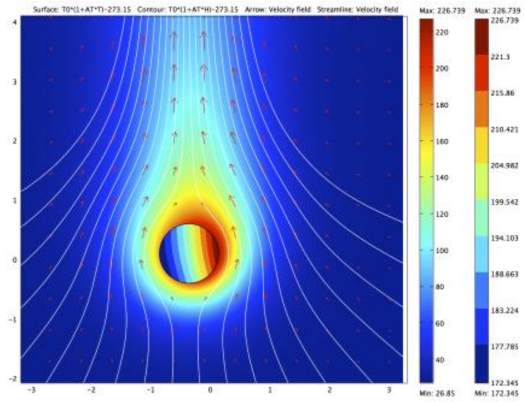
$$\psi(\vartheta) = \frac{1}{2}[\cos(\min\{\pi, \max[0, \theta_A - \vartheta]\}) - \cos(\max\{0, \min[\pi, \theta_B - \vartheta]\})].$$

Mesh

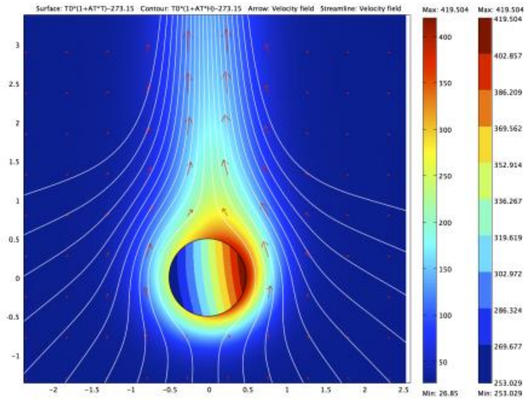


- Number of elements depends on Rayleigh number.
- 20K-40K elements.
- UMFPACK direct linear system solver.

Isothermal and uniform heating results found to be in good agreement with literature.

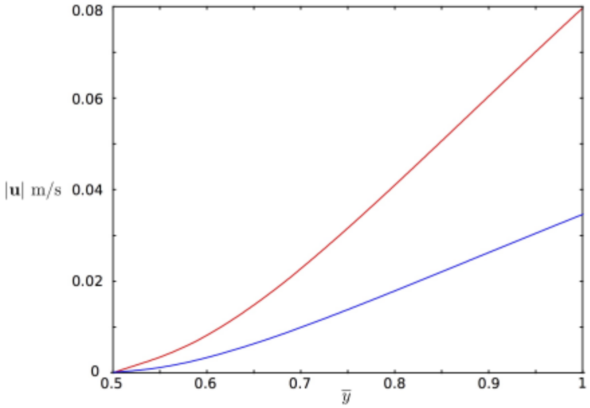


(a) $l = 2$ mm and $J_0 = 20$ kW/m^2



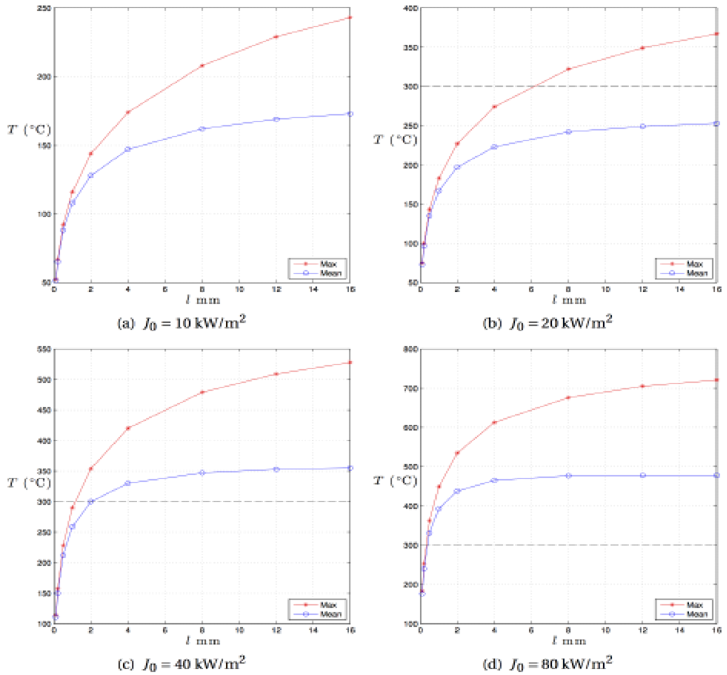
(b) $l = 4$ mm and $J_0 = 40$ kW/m^2

Flow and temperature profiles.



Flow speed against vertical position above cylinder for 2 mm (blue) and 4 mm (red) cylinders.

- 2mm and 4mm cylinders considered.
- Larger temperature profiles for larger (and hotter) cylinders.
- Stronger buoyant flow above larger (and hotter) cylinders.

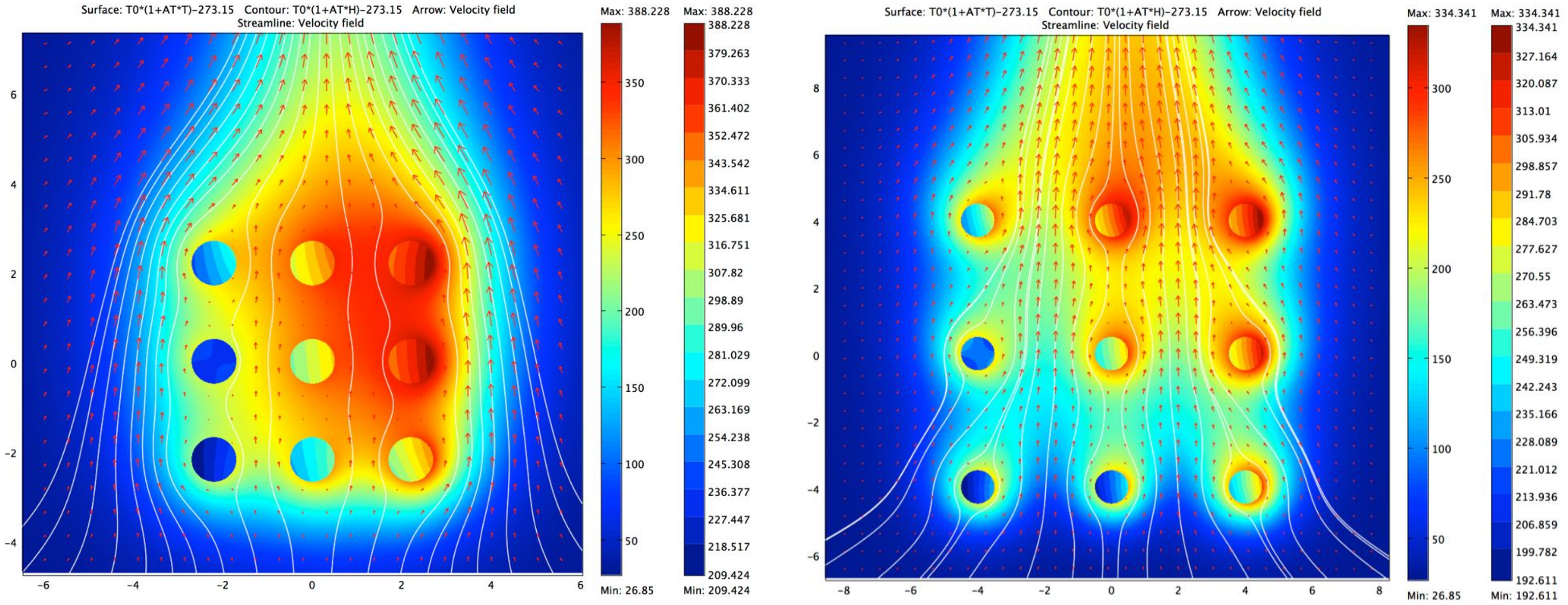


Cylinder temperatures for various cylinder sizes and heating rates.

- Larger heating rate leads to larger average and maximum temperatures.
- Larger cylinders lead to larger temperatures.
- Significant flammable vapour produced at around 300°C.
- Larger fuels produce more flammable vapour.
- More flammable vapour produced at larger heating rates.

Summary

- 2D laminar natural convection flow around cylinder.
- Heat received from a hot panel.
- Larger cylinders found to produce significantly more flammable vapour.
- However, stronger vertical flow around larger cylinders.
- Stronger flow would dilute the mixture thus reducing the possibility of ignition.


Surface: T0*(1+AT*T)−273.15 Contour: T0*(1+AT*H)−273.15 Arrow: Velocity field
Streamline: Velocity field
Max: 388.228
Min: 26.85
Max: 388.228
388.228
379.263
370.333
361.402
352.472
343.542
334.611
325.681
316.751
307.82
298.89
289.96
281.029
272.099
263.169
254.238
245.308
236.377
227.447
218.517
209.424
Min: 209.424
Surface: T0*(1+AT*T)−273.15 Contour: T0*(1+AT*H)−273.15 Arrow: Velocity field
Streamline: Velocity field
Max: 334.341
Min: 26.85
Max: 334.341
334.341
327.164
320.087
313.01
305.934
298.857
291.78
284.703
277.627
270.55
263.473
256.396
249.319
242.243
235.166
228.089
221.012
213.936
206.859
199.782
192.611
Min: 192.611

(a) $S_D = 2.2$.

(b) $S_D = 4$.