Natural convection around horizontal cylinders

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Introduction: The flow around a horizontal cylinder, which is subjected to non-uniform heat from a panel, is studied numerically to gain an insight into a flame-front preheating vegetation during a wildfire. There are also many industrial applications of the study including refrigeration, ventilation and the cooling of electrical components. The possibility of attaining flammability conditions, which occur at around 300ºC for wood-based fuels, is of particular interest. This is explored for a variety of cylinder diameters and heating rates from the hot panel which represents a flame-front.

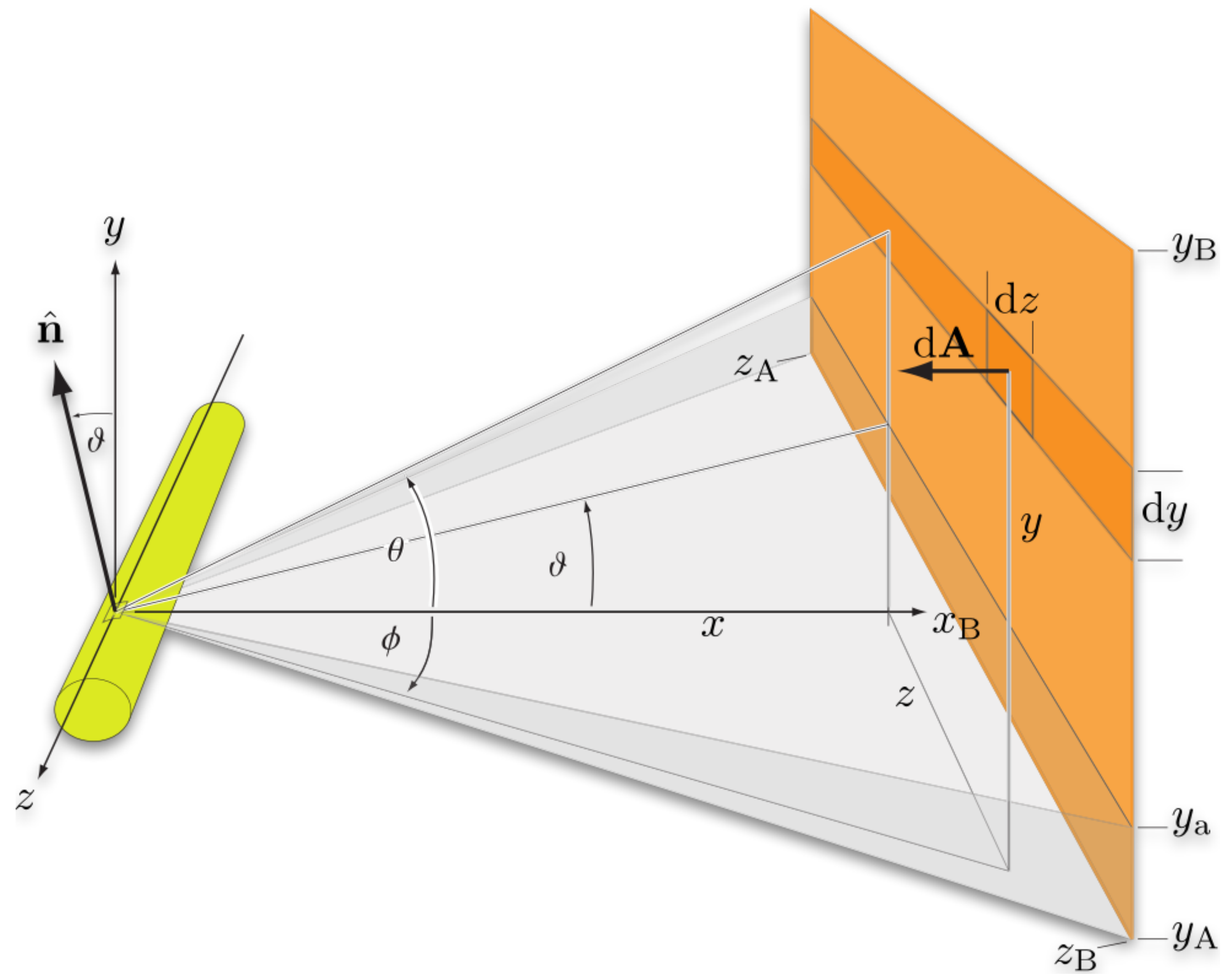
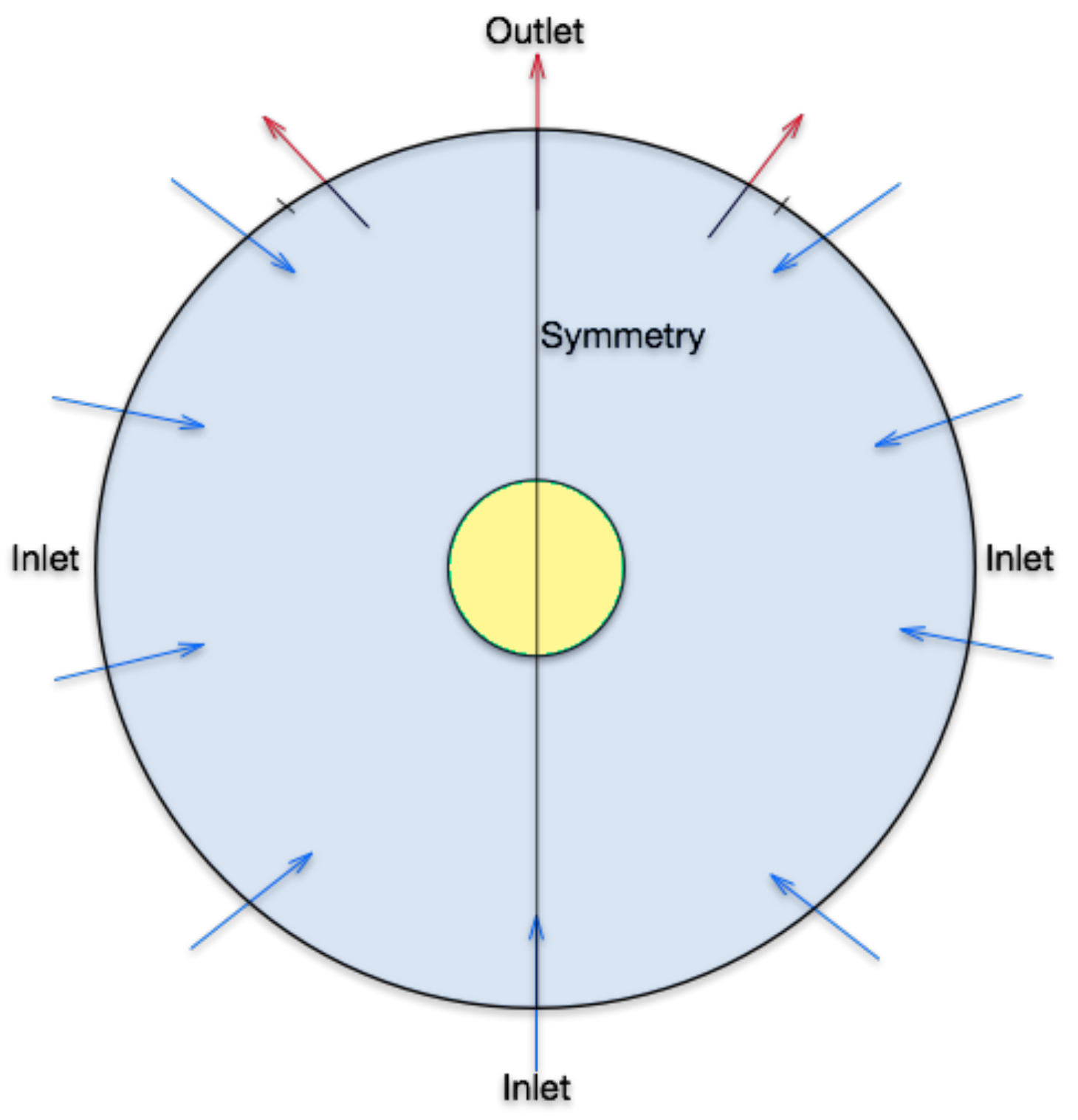


Figure 1. Schematic of cylinder heated by hot panel.

Model: Weakly Compressible Navier-Stokes, Convection and Conduction, and Heat Transfer by Conduction COMSOL Multiphysics 3.5a applications are used to solve the natural convection model with an UMFPACK direct linear system solver. A stationary analysis was carried out using adaptive mesh refinement. The governing equations were nondimensionalised before they were inserted into the the relevant application. Two important parameters of the study are the Prandtl and Rayleigh numbers.



$$\rho \mathbf{u} \cdot \nabla \mathbf{u} + \nabla P = \mathrm{Pr}\,(\nabla \cdot \boldsymbol{\tau} + \mathrm{Ra}\,\rho T\,\mathbf{j})$$

$$\nabla \cdot \rho \mathbf{u} = 0$$

$$\rho c_p \mathbf{u} \cdot \nabla T = \nabla \cdot \lambda \nabla T$$

$$\nabla \cdot \lambda_s \nabla \Theta = 0$$

Boundary conditions are the usual no-slip and continuity of temperature as well as a heat flux boundary condition which describes the non-uniform heating.

Figure 2. Inlet and outlet conditions.

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

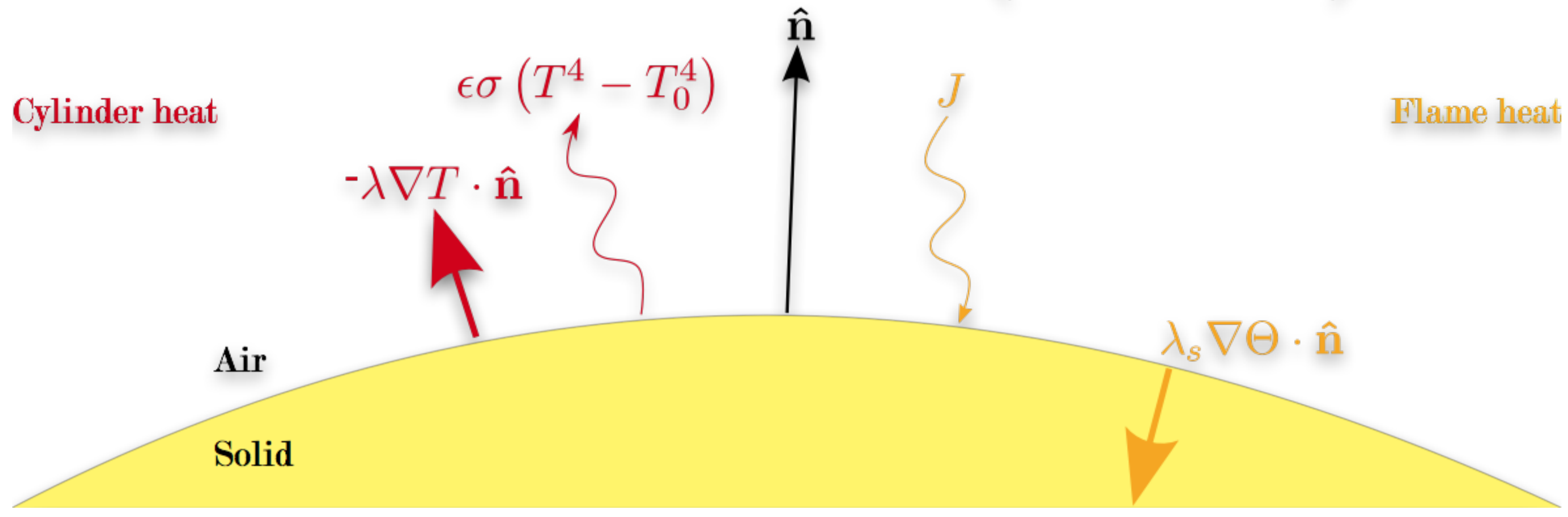
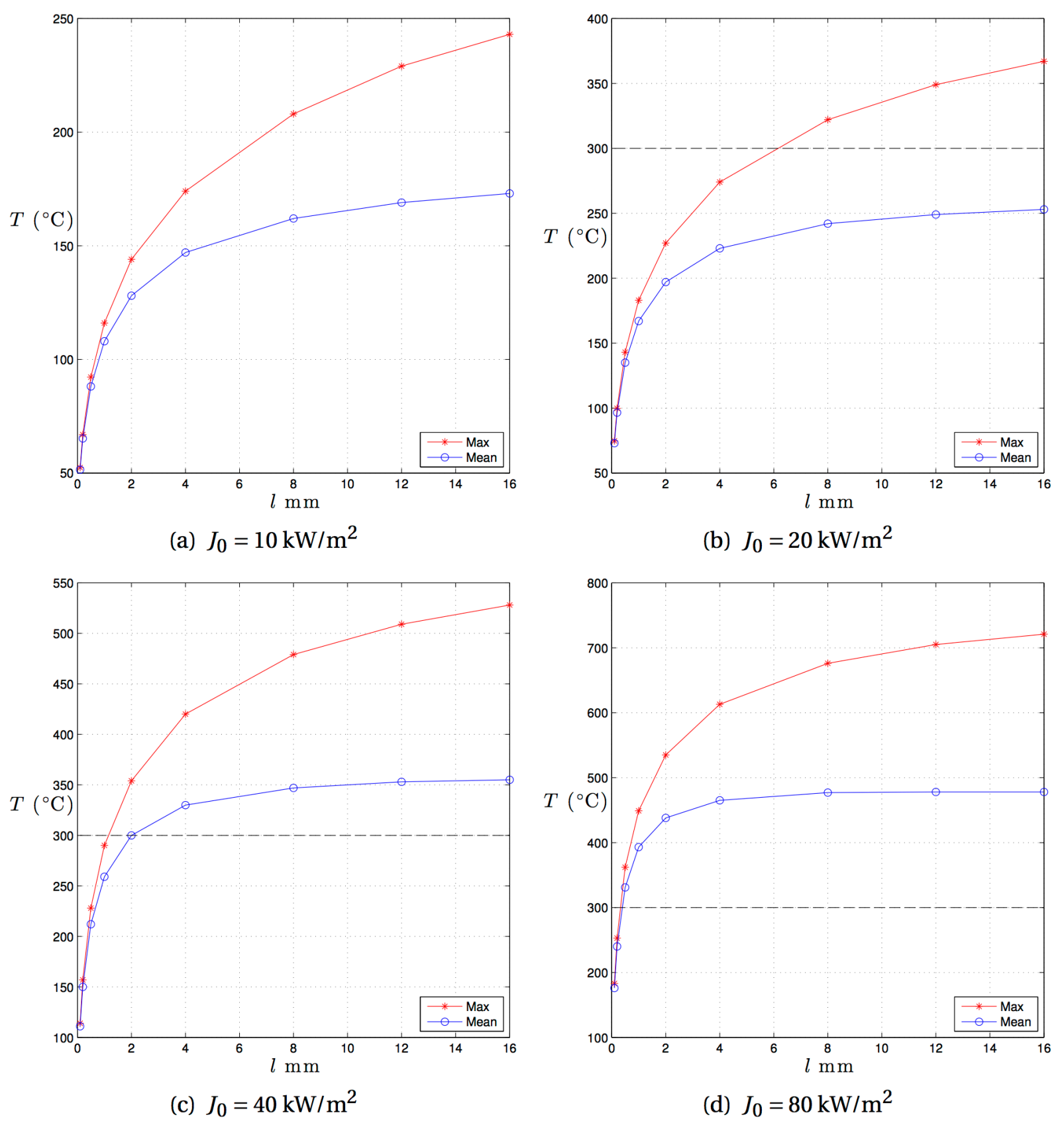


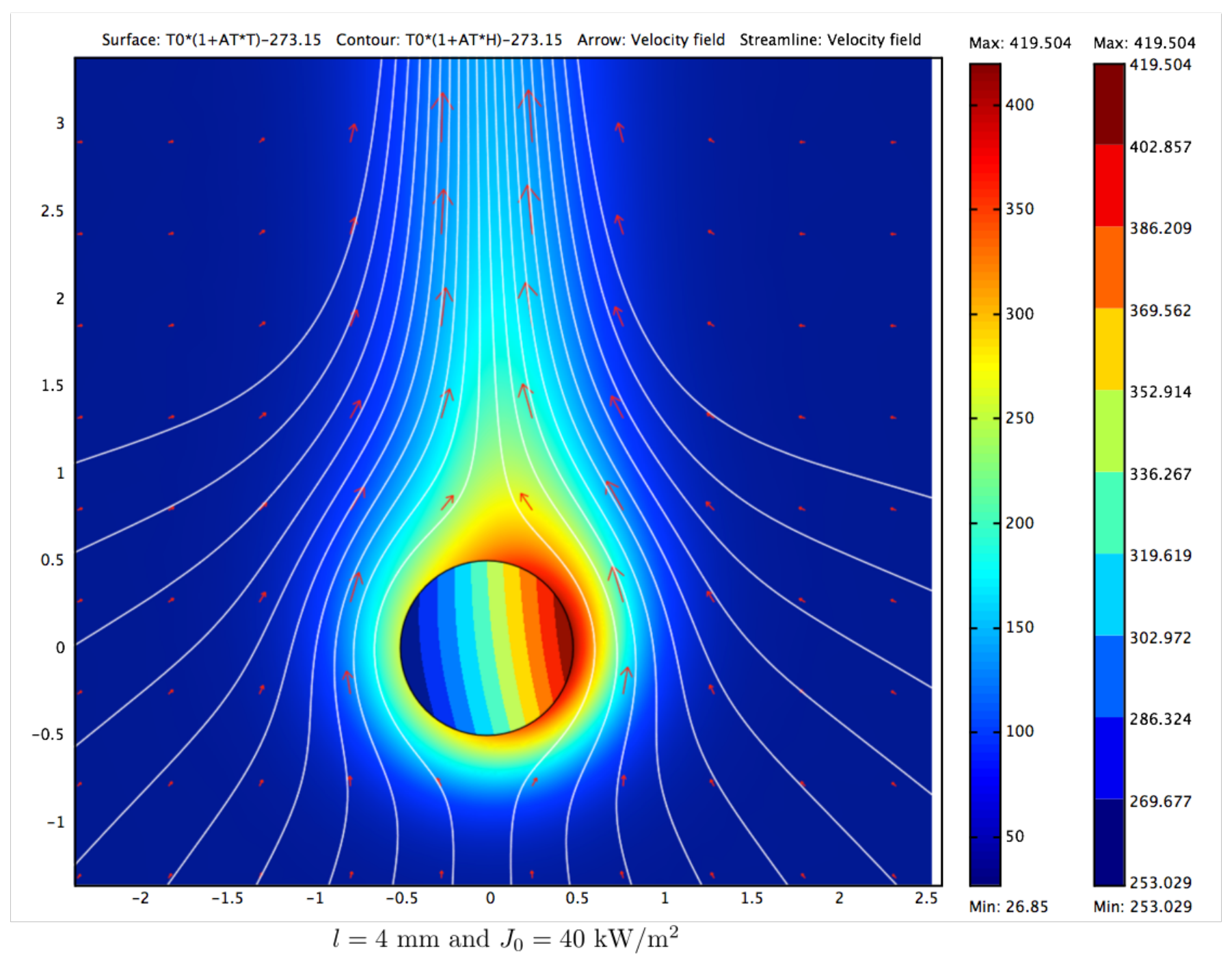
Figure 3. Heat flux boundary condition with non-uniform heating.

Results: It is found that smaller cylinders attain lower temperatures when exposed to the same heating rate as larger cylinders. This suggests that larger fuels are more likely to support flames in a wildfire.



(a) $J_0 = 10\,\mathrm{kW/m^2}$ (b) $J_0 = 20\,\mathrm{kW/m^2}$ (c) $J_0 = 40\,\mathrm{kW/m^2}$ (d) $J_0 = 80\,\mathrm{kW/m^2}$

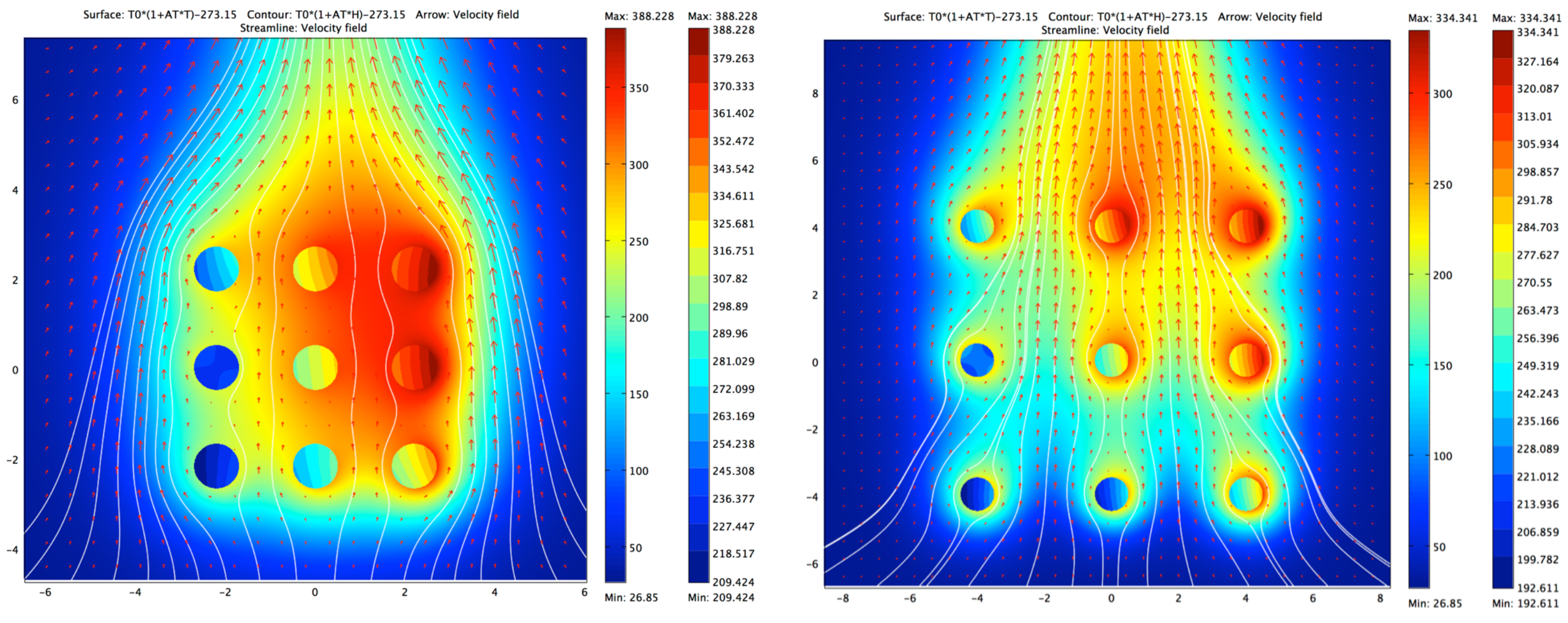
Figure 4. Cylinder temperatures.



$l = 4$ mm and $J_0 = 40\,\mathrm{kW/m^2}$

Figure 5. Flow and temperature profiles.

Results are also obtained for multiple cylinders being exposed to radiant heat where shadowing effects are taken into account to calculate the non-uniform heating rate on each cylinder. The cylinder spacing has an important role in determining the flow and temperature profile of the cylinders.



(a) $S_D = 2.2$. (b) $S_D = 4$.

Figure 6. Multiple cylinders with different cylinder spacing.

Conclusions: The results suggest that though the temperatures are greater for larger cylinder, the flow is stronger too. Hence the flammable vapour that builds up around the cylinder is convected away due to the buoyant flow. This would tend to dilute the mixture thus reducing the possibility of ignition.

References:

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