Natural Convection Around Horizontal Cylinders Subjected to Non-uniform Heating

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Abstract

The laminar natural convection flow around a horizontal cylinder, which is subjected to non-uniform heat, is studied numerically. The cylinder receives heat from a radiating panel (Figure 1) which results in a buoyant flow. The primary reason for this study is to gain an insight into a flame-front preheating vegetation during a wildfire [1]. However there are many industrial applications, including refrigeration, ventilation and the cooling of electrical components, for which the present study may be applicable [2, 3].

`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 relevant application [4]. Two important parameters of the study are the Prandtl and Rayleigh numbers.

Test problems with isothermal and uniform heating conditions were carried out in order to verify the accuracy of the model. Results were found to be consistent with the literature [5,6,7]. This can be seen in Figure 2 where the Nusselt number is the ratio of convective to conductive heat transfer across a boundary. The Nusselt number gives an ideal measurement to compare numerical results as it takes into account both heat and flow effects. The table shows a good agreement with the benchmark results of Saitoh et al. [7]. Reradiation effects and variable air properties are found to have a marked effect on the flow around the horizontal cylinder. The experimental setup of Cohen and Finney [8] is used for a numerical study of their results. It is found that smaller cylinders attain lower temperatures when exposed to the same heating rate as larger cylinders (Figure 3). This suggests that larger fuels are more likely to support flames in a wildfire. Results are also obtained for multiple cylinders being exposed to radiant heat where shadowing effects are taken into account to calculate the nonuniform heating rate on each cylinder. The cylinder spacing has an important role in determining the flow and temperature profile of the cylinders (Figure 4).

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.

Reference

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Figures used in the abstract

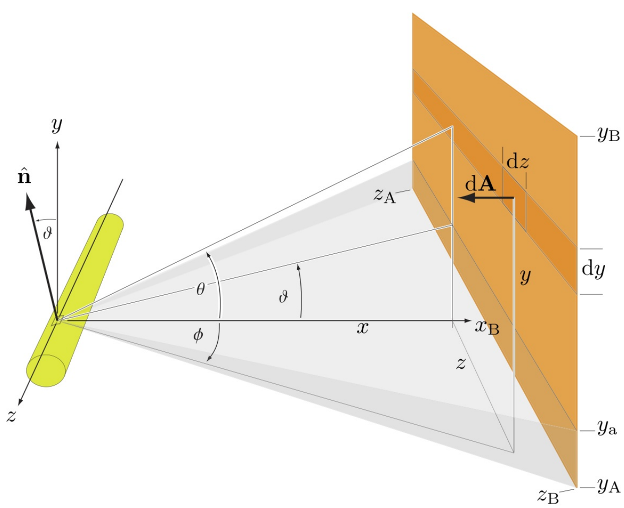


Figure 1: Geometry of horizontal cylinder subjected to heating from a radiating panel.

Ra		$\theta = 0°$	90°	180°	$\overline{\mathrm{Nu}}$
10^3	Present	3.782	3.363	1.217	3.011
	Saitoh et al. [7]	3.813	3.374	1.218	3.024
10^4	Present	5.960	5.389	1.533	4.809
	Saitoh et al. [7]	5.995	5.410	1.534	4.826
10^5	Present	9.752	8.813	1.984	7.939
	Saitoh et al. [7]	9.675	8.765	1.987	7.898

Figure 2: Local and average Nusselt numbers for isothermal circular cylinder compared with the benchmark results of Saitoh et al. [7].

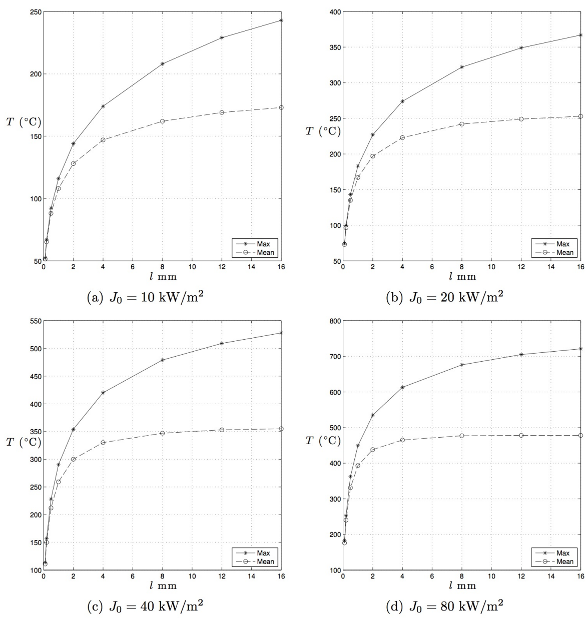
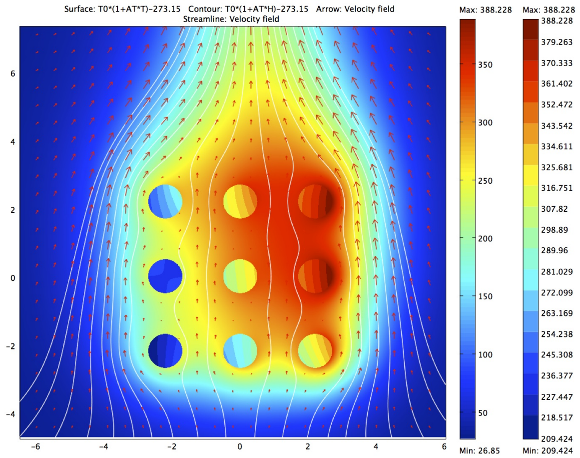
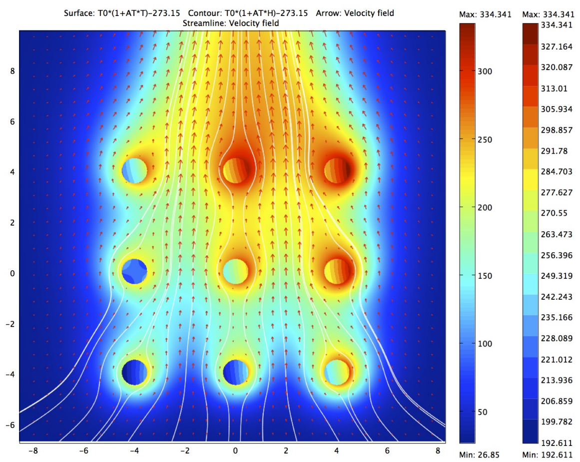


Figure 3: Maximum and average surface temperatures around a horizontal cylinder against a range of sample sizes for various heating rates.



(a) $S_D = 2.2$.



(b) $S_D = 4$.

Figure 4: Temperature profiles, velocity fields and streamlines for an array of horizontally aligned cylinders and different cylinder spacings. Heating rate is 40 kilowatts per square metre and sample size is 1 mm.