Numerical Analysis of the Self-Heating Behaviour of Coal Dust Accumulations

D. Wu, E. Van den Bulck

Department of Mechanical Engineering, KU Leuven, Belgium

KATHOLIEKE UNIVERSITEIT LEUVEN

Self-heating behaviour of dust accumulations is a multi-physics field coupled heat and mass transfer in the porous media. A typical experimental apparatus with a hot storage oven and mesh wire baskets has been taken as the study object. The influence of gas flow velocity, oxygen concentration and ambient temperature on the self-heating behaviour of the dry coal dust sample has been investigated with COMSOL Multiphysics®.

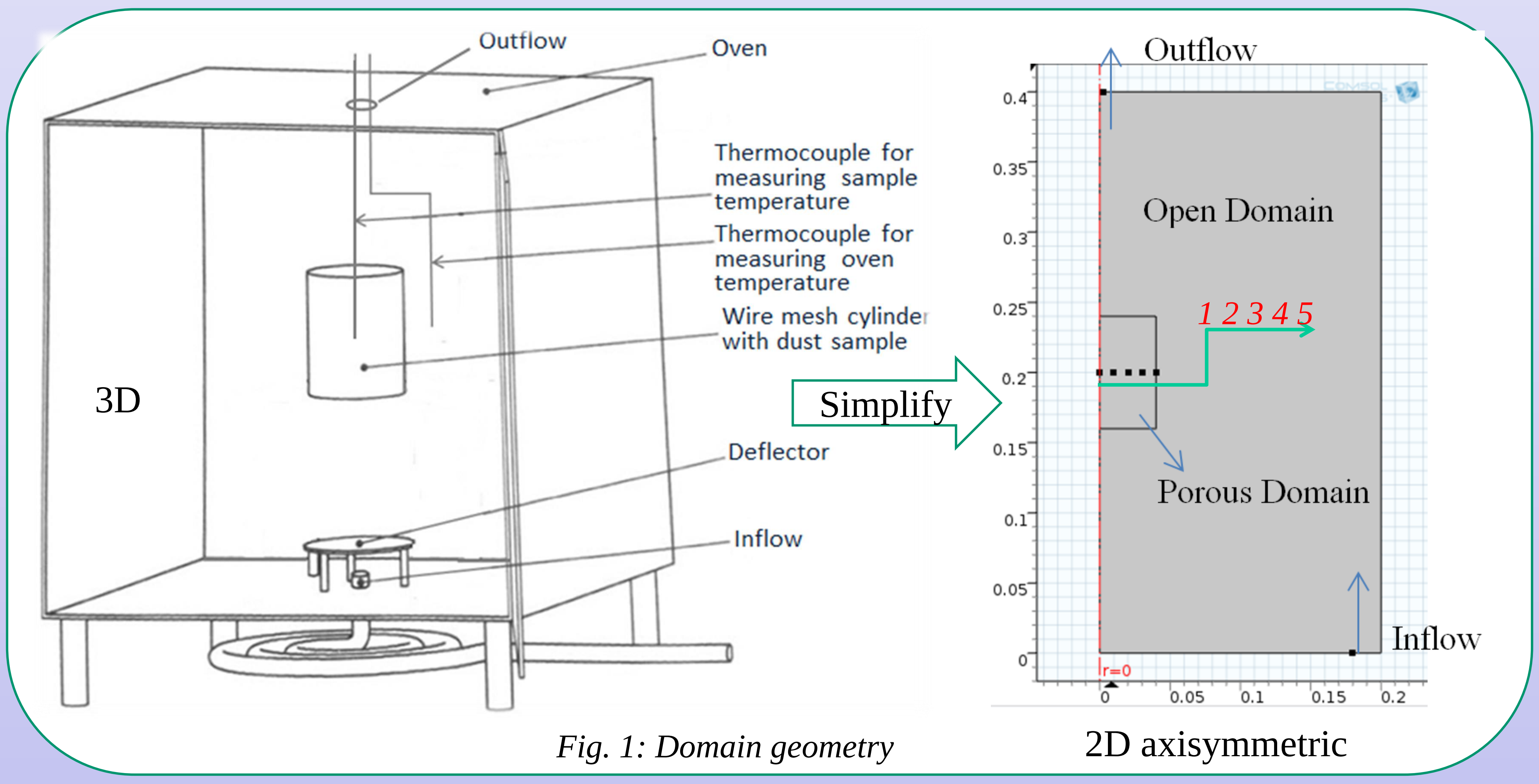

Fig. 1: Domain geometry

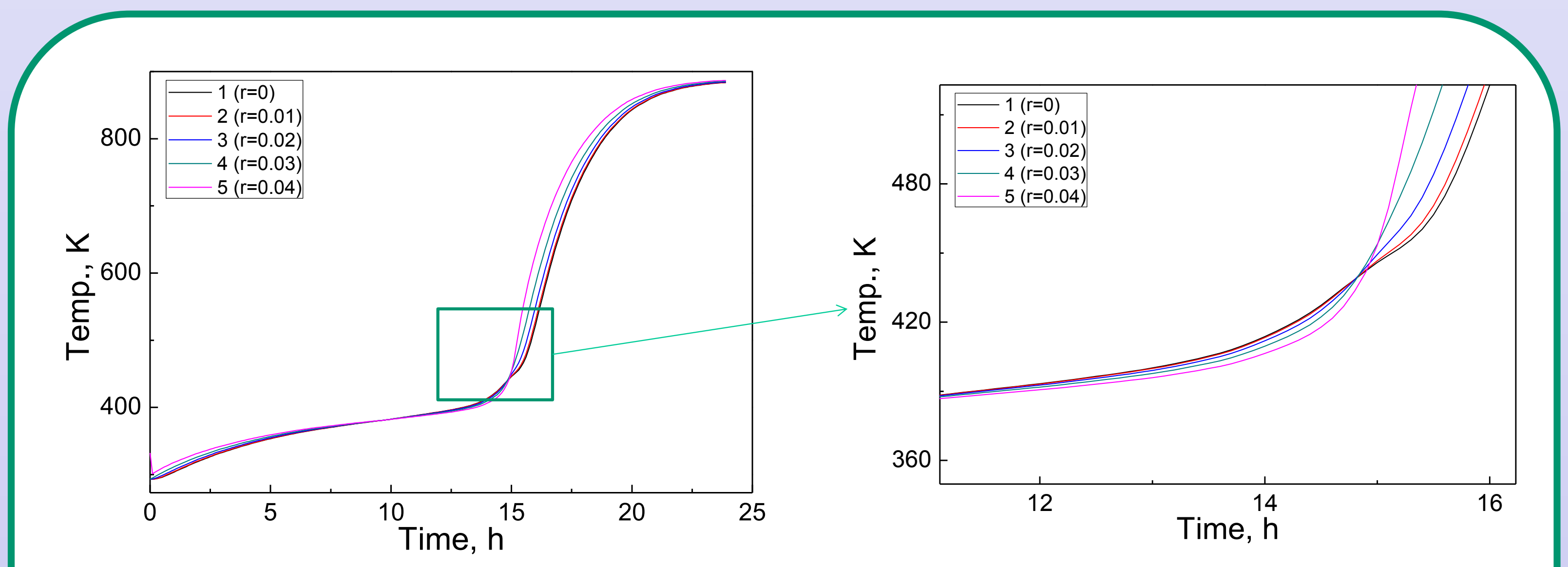

Fig. 3: Temperature profiles of different points on the central line at 21 vol.% O2 with 0.059m/s gas flow and 380.15K

- ***Chemical***

$$\mathrm{Coal} + \mathrm{O_2} \xrightarrow{k} \mathrm{CO_2} + 0.1\mathrm{CO} + \mathrm{heat}$$

$$rate = k \cdot c\mathrm{O_2} \qquad k = A\exp\left(-\frac{E_\mathrm{A}}{RT}\right)$$

- ***Free and Porous Media Flow***

Open domain: $$\rho\frac{\partial \mathbf{u}}{\partial t} = \nabla\cdot[-p\mathbf{I} + \mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T]$$

Porous domain:

$$\frac{\rho}{\varepsilon_\mathrm{b}}\frac{\partial \mathbf{u}}{\partial t} = \nabla\cdot[\frac{\mu}{\varepsilon_\mathrm{b}}(\nabla\mathbf{u} + (\nabla\mathbf{u})^T) - p\mathbf{I}] - \frac{\mu}{\kappa}\mathbf{u}$$

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

- ***Species Transport in Porous Media***

Open domain: $$\frac{\partial c_i}{\partial t} - \nabla(D_i\nabla c_i) + \mathbf{u}\cdot\nabla c_i = 0$$

Porous domain:

$$\varepsilon_\mathrm{b}\frac{\partial c_i}{\partial t} + \nabla(-\varepsilon_\mathrm{b}\tau_{\mathrm{F},i}D_{F,i}\nabla c_i) + \mathbf{u}\cdot\nabla c_i = R_i$$

- ***Heat Transfer in Porous Media***

Open domain: $$\rho C_\mathrm{p}\frac{\partial T}{\partial t} + \rho C_\mathrm{p}\mathbf{u}\cdot\nabla T = \nabla\cdot(k_\mathrm{g}\nabla T)$$

Porous domain:

$$(\rho C_\mathrm{p})_\mathrm{eq}\frac{\partial T}{\partial t} + \rho C_\mathrm{p}\mathbf{u}\cdot\nabla T = \nabla\cdot(k_\mathrm{eq}\nabla T) + Q$$

$$(\rho C_\mathrm{p})_\mathrm{eq} = (1-\varepsilon_\mathrm{b})\rho_\mathrm{p}C_\mathrm{p,p} + \varepsilon_\mathrm{b}\rho_\mathrm{g}C_\mathrm{p}$$

$$k_\mathrm{eq} = (1-\varepsilon_\mathrm{b})k_\mathrm{b} + \varepsilon_\mathrm{b}k_\mathrm{g}$$

Table 1: Input parameters

λ Thermal conductivity ($\mathrm{W\cdot m^{-1}\cdot K^{-1}}$)	0.1
C_p Specific heat capacity ($\mathrm{J\cdot kg^{-1}\cdot K^{-1}}$)	1.1e3
h Heat transfer coefficient ($\mathrm{W\cdot m^{-2}\cdot K^{-1}}$)	
ρ_p Density of coal ($\mathrm{kg\cdot m^{-3}}$)	1.2e3
ρ_b Bulk Density ($\mathrm{kg\cdot m^{-3}}$)	600
$\varepsilon = \frac{\rho_\mathrm{p}-\rho_\mathrm{b}}{\rho_\mathrm{p}-\rho_\mathrm{g}} \approx 1 - \frac{\rho_\mathrm{b}}{\rho_\mathrm{p}}$ Porosity	0.5
E_a Activation energy in air oxidation ($\mathrm{kJ\cdot mol^{-1}}$)	98
A pre-exponential factor ($\mathrm{s^{-1}}$)	1e7
M_fuel molar weight of coal ($\mathrm{g\cdot mol^{-1}}$)	4e3
ΔH Heat of reaction ($\mathrm{kJ\cdot mol^{-1}\ O_2}$)	400
r_p average coal particle radius (m)	1e-3

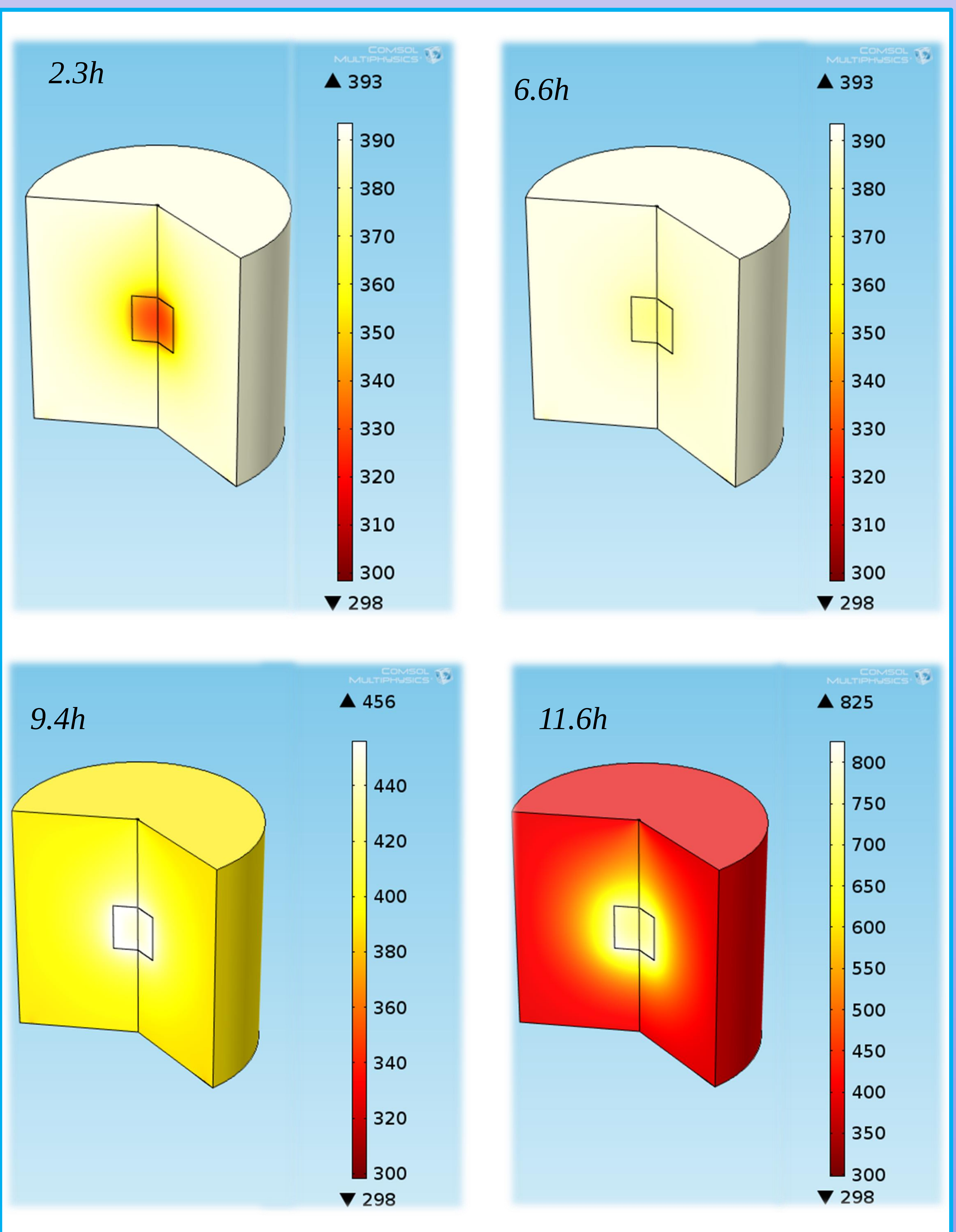

Fig. 2: Temperature profiles (21 vol.% O2 at 388.15K with 0.059m/s gas flow

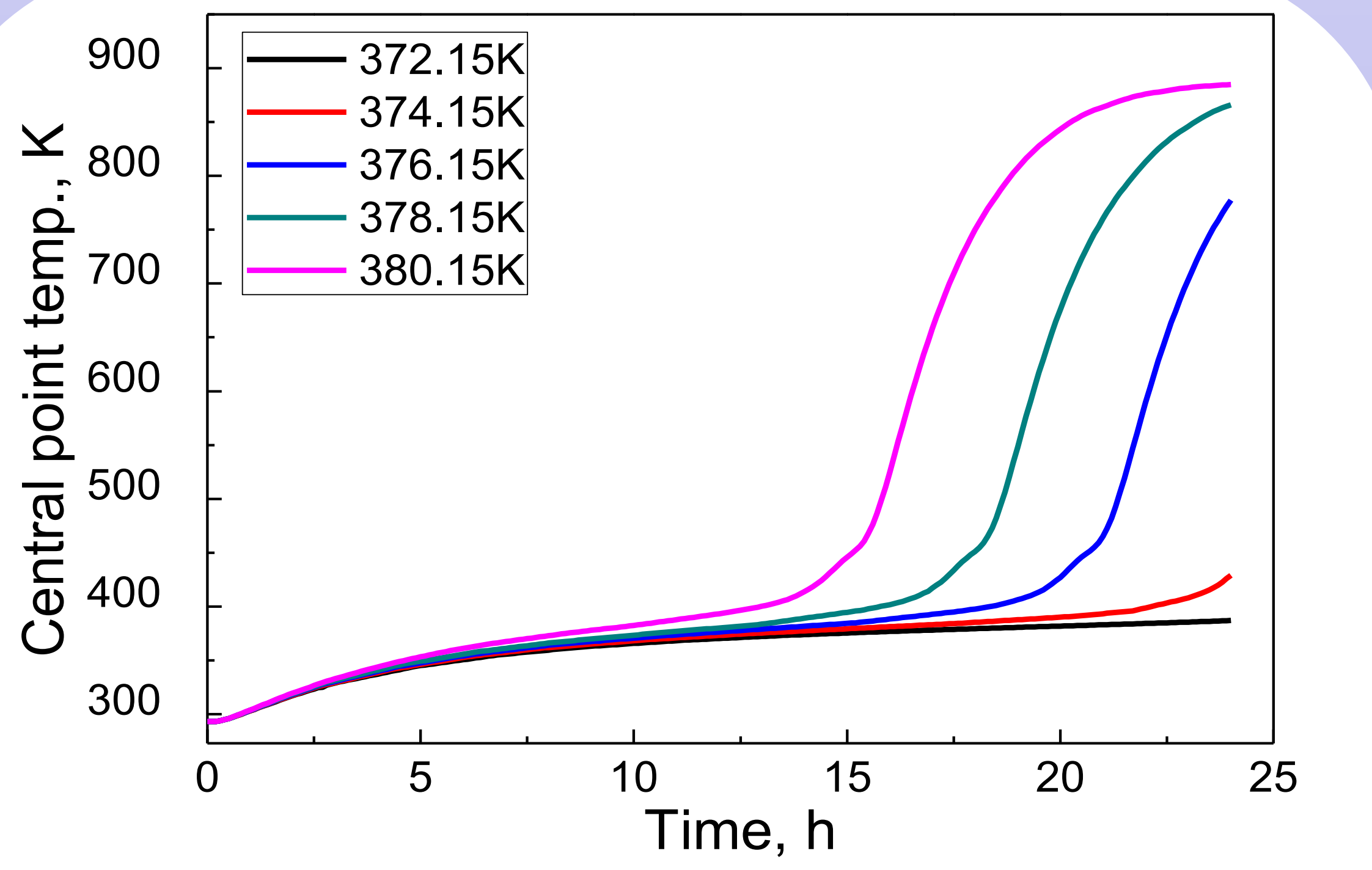

Fig. 4: Temperature evolution of the central point at 21 vol.% O2 with 0.059m/s gas flow at various ambient temperatures

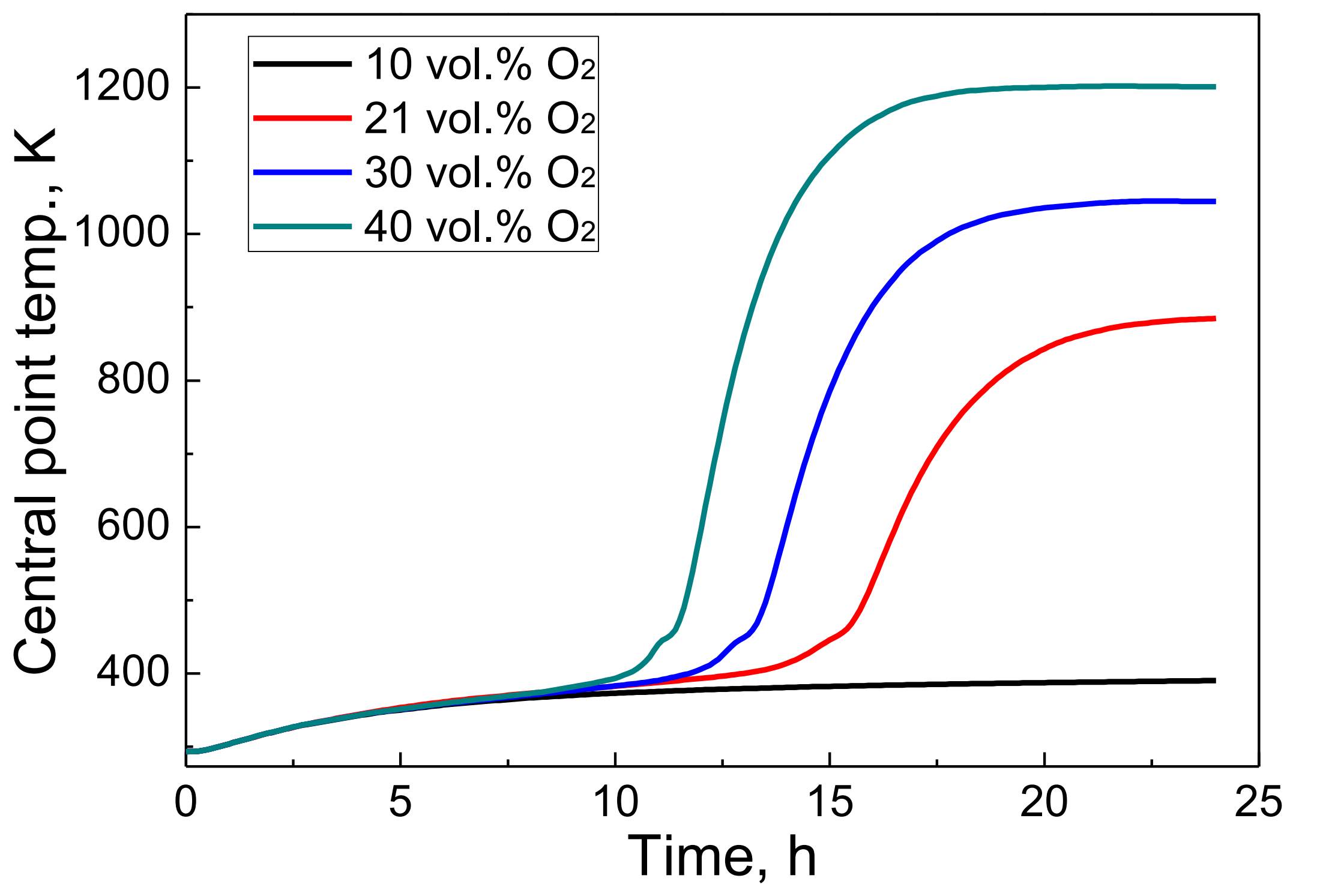

Fig. 5: Temperature evolution of the central point at 380.15K with 0.059m/s gas flow at various oxygen concentrations

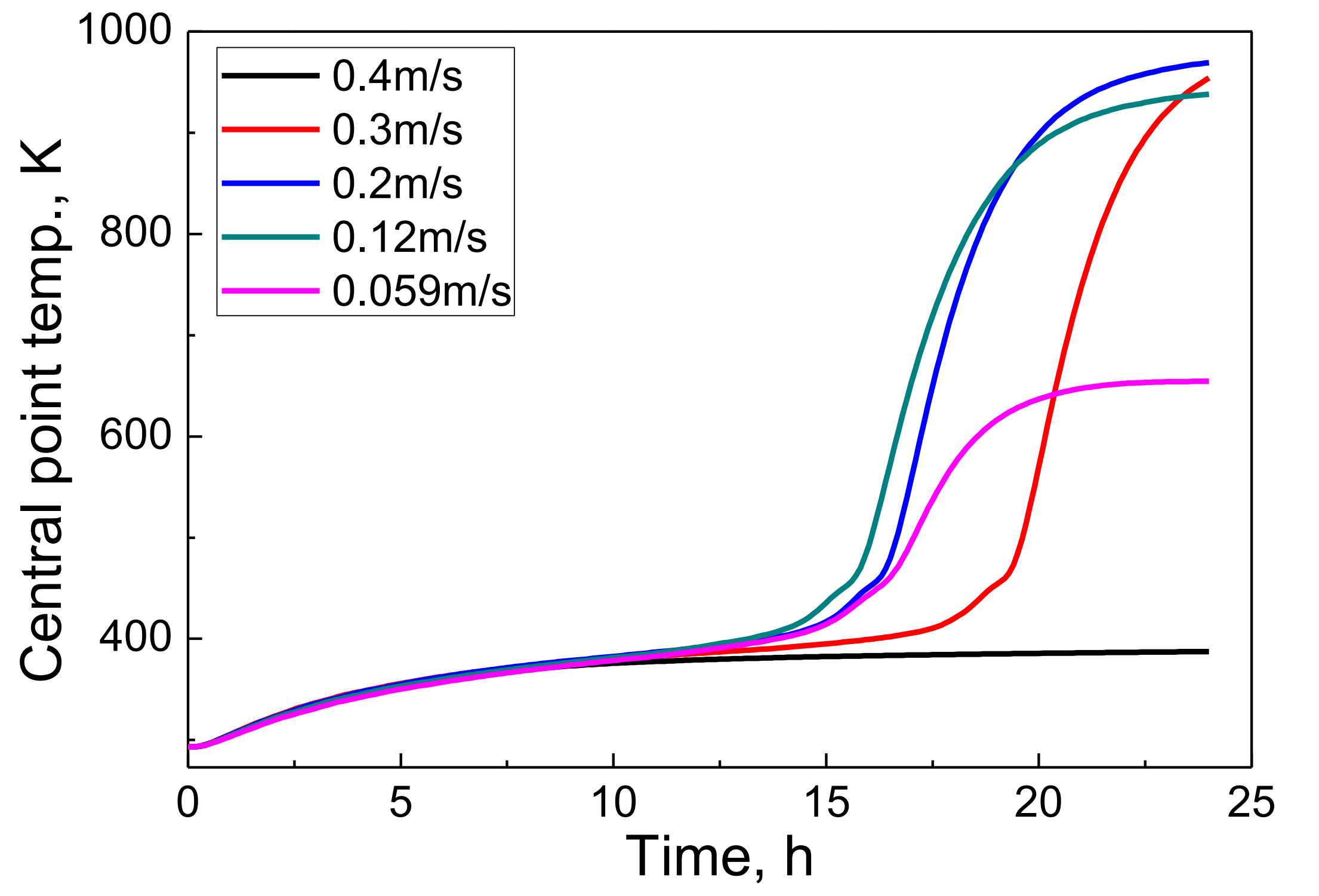

Fig. 6: Temperature evolution of the central point at 380.15K with 21 vol.% O2 at various inflow velocities

Conclusions and future work

- ✓ Ignition delay time decreases with increasing ambient temperature and oxygen concentration;
- ✓ The maximum temperature can be reached after ignition increases with increasing ambient oxygen concentration;
- ✓ The inflow velocity has both positive and negative affects on self-heating. The critical velocity is between 0.12 to 2m/s.
- ❖ The influence of particle size and depletion of coal should be taken into consideration.

References
[1] CEN, Determination of the Spontaneous Ignition Behavior of Dust Accumulations. European Standard EN15188, European Committee for Standardization, Brussels, 2007.
[2] U. Krause, M. Schmidt, C. Lohrer, A Numerical Model to Simulate Fires in Bulk Materials and Dust Deposits, J. Loss Prev. Process Ind. , 19, 218-226 (2006).
[3] L. Yuan, A. C. Smith. CFD modeling of spontaneous heating in a large-scale coal chamber, J. Loss Prev. Process Ind. 22, 426-433 (2009).
[4] H. Zhu, Z. Song, B. Tan, Y. Hao. Numerical investigation and theoretical prediction of self-ignition characteristics of coarse coal stockpiles, J. Loss Prev. Process Ind. 26, 236-244 (2013).

COMSOL CONFERENCE 2014 CAMBRIDGE

RelCOm$_2$ Reliable Combustion

Excerpt from the Proceedings of the 2014 COMSOL Conference in Cambridge