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

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Abstract

Introduction
The self-ignition behavior of combustible dusts depends on their chemical composition as well as on related substance properties. It also depends on the size and geometry of the body of material, the ambient temperature and last but not least on the ambient atmosphere. In some practical applications, dust accumulations may expose at reduced oxygen concentration (e.g., inerting) or elevated oxygen conditions (e.g., oxy-fuel combustion). Basket method is one of the typical lab-scale methods for self-ignition behavior of dust accumulations assessment. Generally, dust samples are placed into a gauze container of a known size, which is then suspended in an isoperibol oven of a given temperature. The temperature at the center of the container (Tc) and the oven temperature (To) are measured using thermocouples. A typical experimental setup for hot storage test to determine the critical spontaneous ignition parameters of dust accumulations is given in Figure 1.

Model Approach
The problem of self-ignition behavior is a multiphysics field coupled heat and mass transfer in the porous media. For a dry or dust sample with low-moisture, a simplified reaction model is employed to investigate the critical ambient temperature and oxygen concentration of the self-ignition of coal dust at given conditions.
Coal + O2 → CO2 + heat
The reaction rate is given by:
rate = k*cO2
where rate constant k is temperature concentration dependent according to the Arrhenius equation and cO2 is the concentration of oxygen.
-- Free and Porous Media Flow (the shrinkage of dust sample with heating is not considered, so porosity is supposed to be constant),
-- Heat Transfer in Porous Media (the heat radiation of the oven walls is ignored, so we can simplify the geometry to a 2D axial symmetry),
-- Species Transport in Porous Media (adsorption and dispersion effects are neglected).

Results
Figure 2 shows the velocity field in the oven and basket domain. The velocity gradient is significant only at the outlet because the inlet velocity is quite low (gas flow is 120 L/h). Figure 3 shows the temperature distributions of the oven at the moments of 2 h and 9 h. Figure 4

illustrates the oxygen concentration effect on the induction time and maximum combustion temperature of self-ignition.

Conclusion

The influence of oxygen concentration on self-ignition behavior has been investigated with COMSOL Multiphysics®. The computed results of the numerical model agree with the obtained experimental results, particularly at the self-heating period (T < 673.15 K). So the model is validated to predict the critical conditions of self-ignition at other given conditions, such as the industrial size of the bulk material, the atmosphere of oxy-fuel combustion. In order to build a more accurate model, an extra dimension is proposed to use with taking the particle size and the surface of particle into account. The kinetic model should be improved as well in the future work.

Reference

[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, Journal of Loss Prevention in the Process Industries, 19, 218-226 (2006).
[3] H. Zhu, Z. Song, B. Tan, Y. Hao. Numerical investigation and theoretical prediction of self-ignition characteristics of coarse coal stockpiles, Journal of Loss Prevention in the Process Industries, 26, 236-244 (2013).

Figures used in the abstract

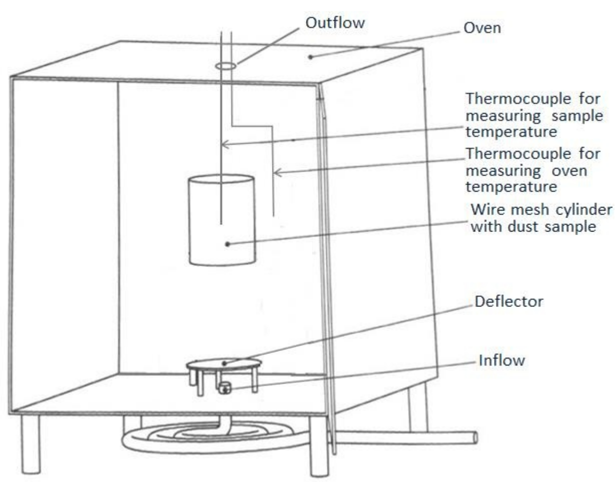

Figure 1: Schematic of the experimental apparatus.

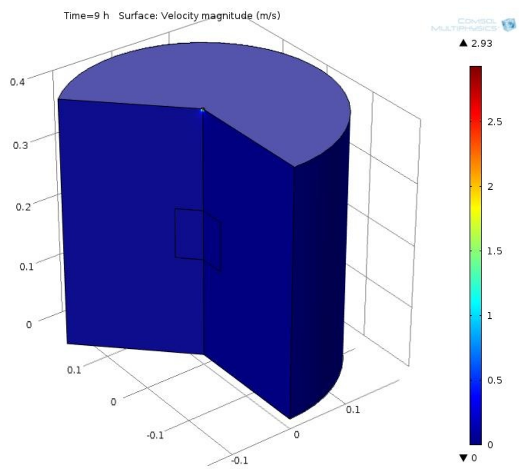

Figure 2: Velocity field in the oven with the heat of reaction is taken into account.

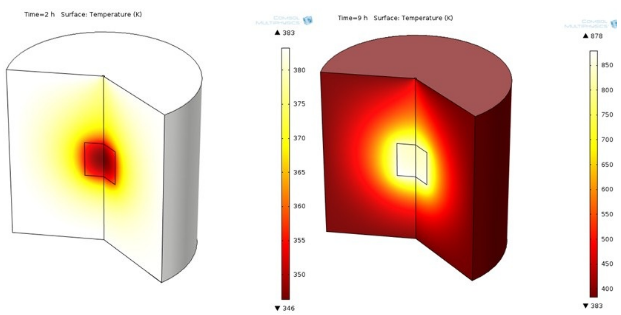

Figure 3: Temperature distributions in the basket at 2h and 9h when To = 383.15K.

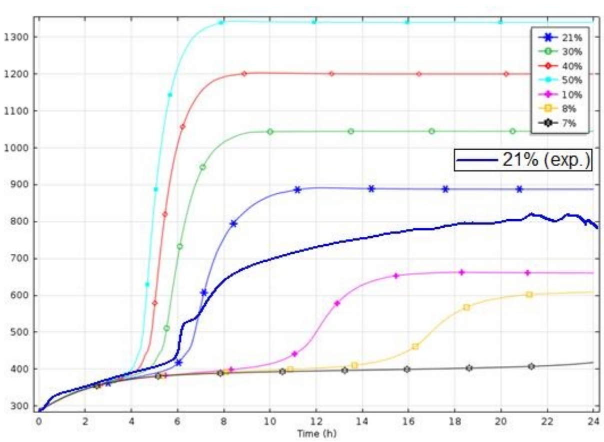

Figure 4: The influence of oxygen concentration on self-ignition temperature.