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BEng (Mechanical), Dalhousie University, 2011

DEPARTMENT OF PROCESSING ENGINEERING AND APPLIED SCIENCE

TITLE OF THESIS:	Burning Velocity and Lower Flammability Limits of Hybrid Mixtures Containing Combustible Dust and Flammable Gas
TIME/DATE:	11:00 am, Monday, April 16, 2018
PLACE:	Room 430, The Computer Science Building, 6050 University Avenue

EXAMINING COMMITTEE:
Dr. Ö. L. Gülder, Institute of Aerospace Studies, University of Toronto (External Examiner)

Dr. Faisal Khan, Department of Process Engineering, Memorial University (Reader)

Dr. Michael Pegg, Department of Process Engineering and Applied Science, Dalhousie University (Reader)

Dr. Robert Ripley, Lloyd's Register/Department of Process Engineering and Applied Science, Dalhousie University (Co-Supervisor)

Dr. Paul Amyotte, Department of Process Engineering and Applied Science, Dalhousie University (Supervisor)

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CHAIR:	Norman Schepp, PhD Defence Panel, Faculty of Graduate Studies

ABSTRACT

Hybrid mixtures of combustible dust and flammable gas may demonstrate increased burning velocities and reduced lower flammability limits (LFL) over the fuels individually. This can increase explosion likelihood and severity in industrial operations and makes it difficult to develop and implement explosion prevention and protection strategies. The objective of this work is to extend the current knowledge of laminar burning velocity and LFLs of hybrid mixtures. This is achieved using computational fluid dynamics (CFD) modeling to analyze flame structure, burning velocity, and propagation limits. The computational model includes global approximations to molecular transport, and the accuracy of four reaction mechanisms with increasing complexity are explored.

Simulations investigating the structure of coal dust flames, the effect of equivalence ratio on hybrid mixtures, and coupling interaction between gas flame propagation and particle heating, devolatilization, and surface reaction, are explored in this work. These simulations allow combustion regime diagrams to be created for hybrid mixtures. In these diagrams, six regimes are identified: fuel-lean, fuel-rich, volatile-rich, transition flames, kinetic-limited flames, and impeded-gas flames. The characteristics of each regime including flame structure, burning velocity, flame temperature, and flame coupling are evaluated using the CFD model.

Mixing rules for lower flammability limits of methane gas and coal dust mixtures are evaluated based on results from the CFD model. Linear mixing based on Le Chatelier's law is found to agree with the simulation results for 10 micron coal dust particles. Larger particles with 33 micron diameters demonstrated strong flame propagation at concentrations slightly wider than Le Chatelier's Law, but not as wide as Bartknetch's curve. These results indicate that a variable exponent is required in the mixing rule, although the existing relations in the literature with this feature predicted narrowing of the flammability limits that was not shown in the current results.

The accuracy of the CFD model in simulating gas, dust, and hybrid flames is evaluated throughout this work, along with the role of gas-phase reaction mechanisms. The burning velocity for methane flames could be quantitatively captured below equivalence ratios of 0.8 using multistep reaction mechanisms and a unity Lewis number assumption for gas diffusion. The burning velocity is overpredicted by 50 % in this range using a single-step mechanism. For dust and hybrid flames, the single-step reaction mechanism agreed with experimental data on the burning velocity, coupling interaction, and the effect of initial temperature. The computational model also demonstrates qualitative features of coal dust flames that could not be captured by previous models in the literature. Multistep reaction mechanisms show a maximum difference of 10% compared to the single-step mechanism for the dust alone, but are unable to capture propagating flames throughout the entire flammable dust range suggested by experiments in the literature.

The results from this work provide novel classifications for determining burning velocity enhancement for hybrid mixtures, illustrate that linear mixing rules approximately delineate LFLs for coal dust and methane gas, and verify that a CFD model based on a unity Lewis number approach for gas diffusion can correctly capture the burning velocity of dust and hybrid mixtures. These results can be used to guide experimental testing for research programs or hazard assessments, and the CFD model provides an open platform to explore and extend the fundamental knowledge of flame propagation in dust and hybrid mixtures.