101年大學部國際交流甄選專題成果展

Minimum Ignition Energy Transition in High-Pressure Turbulent Environment

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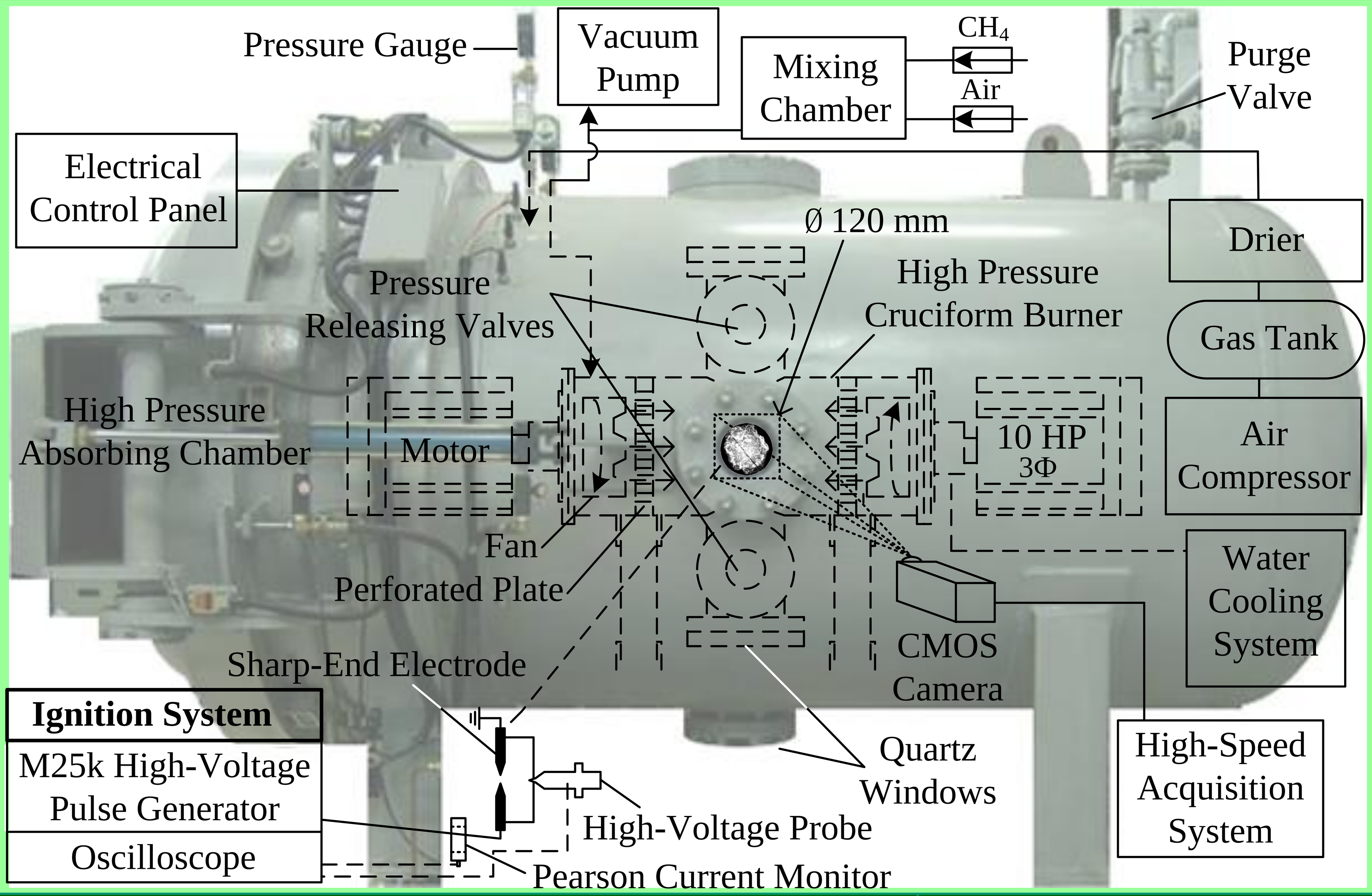
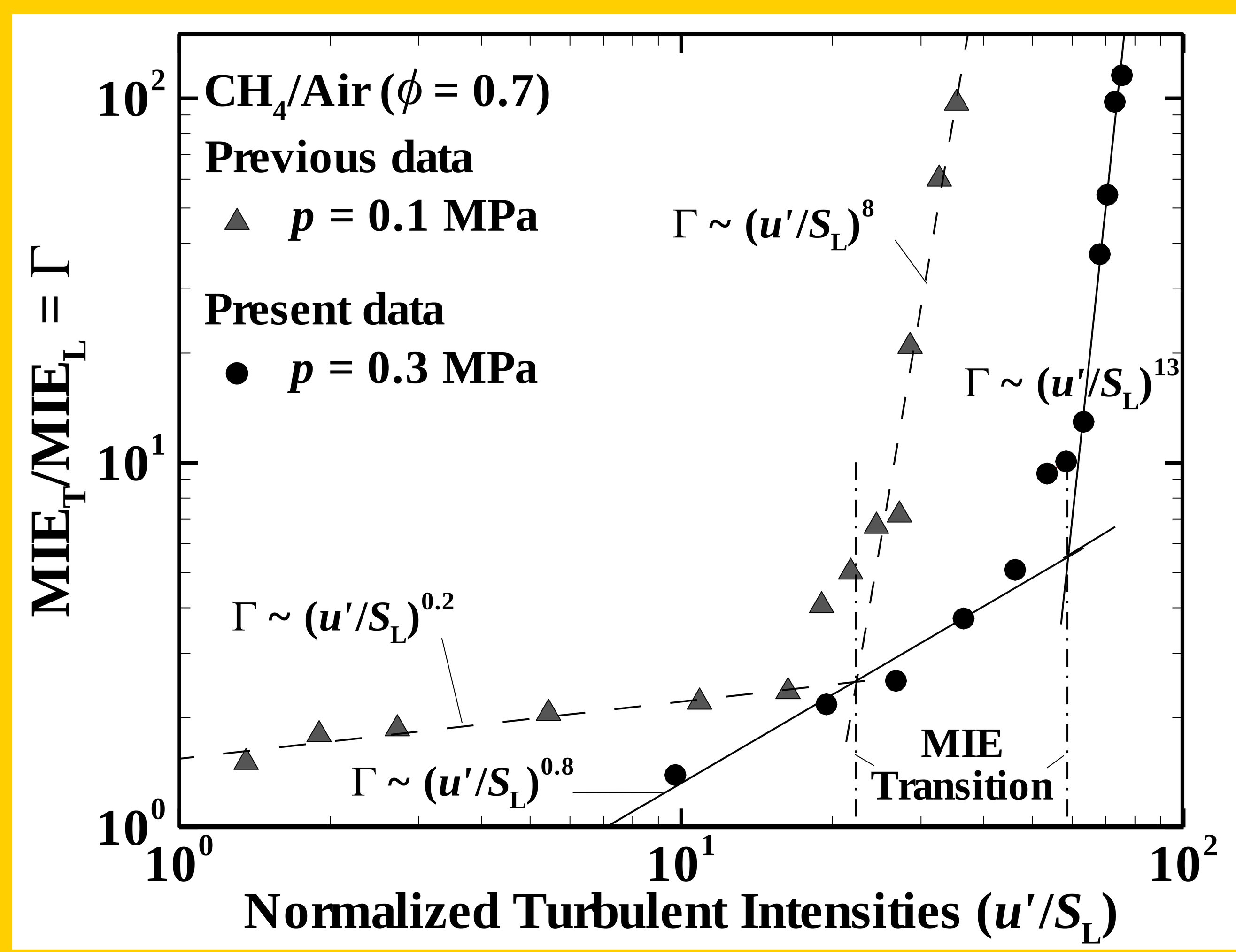
Under both normal and elevated pressure conditions (p = 0.1 and 0.3 MPa), this work measures quantitatively minimum ignition energies (MIE) of lean methane-air mixtures at the equivalence ratio ϕ = 0.7 as a function of turbulent intensities (u'/S_L) up to 100 covering both flamelet and distributed regimes, where S_L is the laminar burning velocity. Experiments are carried out in a high-pressure, double-chamber explosion facility together with a high-power pulse generator that is used to control ignition energies of a spark-electrode at the centre of a large inner cruciform burner. The inner burner lodged in a huge high-pressure absorbing outer chamber is equipped with a pair of counter-rotating fans and perforated plates capable of generating intense near-isotropic turbulence. Two statistical methods used to determine MIE are introduced and compared. Results show that MIE_L at u'/S_L = 0 decreases from 0.73 mJ to 0.23 mJ when p increases from 1 atm to 3 atm and values of MIE_T at 3 atm are much smaller than that at 1 atm for any fixed u'/S_L. It is found that there is an ignition transition, across which the slopes of $MIE_T/MIE_L = \Gamma$ curves with increasing u'/S_L change drastically from linear increase to exponential increase, where the subscripts T and L represent turbulent and laminar values. Moreover, the transition occurs at different critical values of u'/S_L, when p = 1 atm, $(u'/S_L)_c \approx 22$, while $(u'/S_L)_c \approx 60$ when p = 3 atm. A modified reaction zone Péclet number, $Pe^* = Pe(p/p_0)^{-1/4}$, indicating the diffusivity ratio between turbulence and chemical reaction just around the discharged spark kernel with the pressure correction where p_0 = 0.1 MPa, is introduced. The aforesaid two different sets of Γ curves at 1 atm and 3 atm can be merged into a single curve having two drastically different increasing slopes with Pe^* which are separated by a critical $Pe^* \approx 4.6$. Finally, a model is proposed to explain these results.

High-Pressure, Double-Chamber Turbulent Premixed Combustion Facility

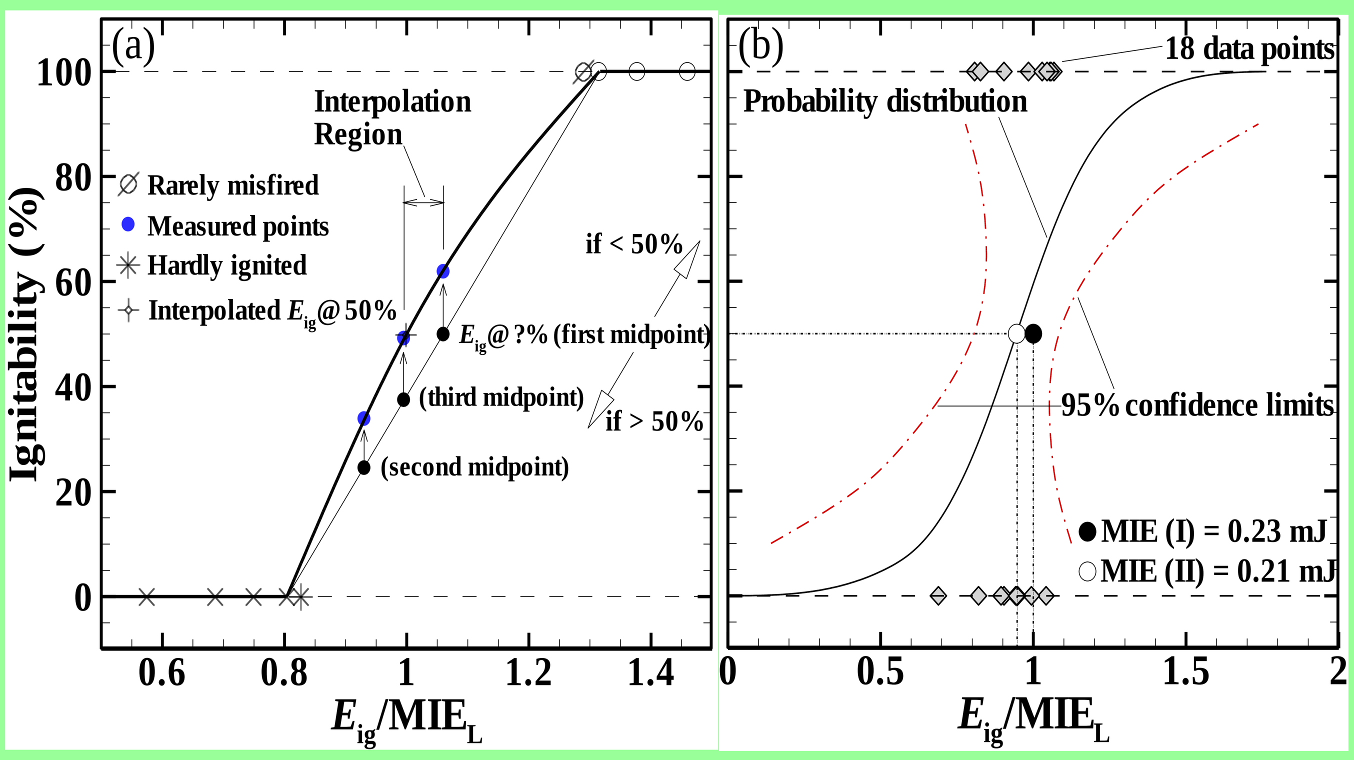


Turbulent Ignition Transitions at p = 0.1 MPa and p = 0.3 MPa



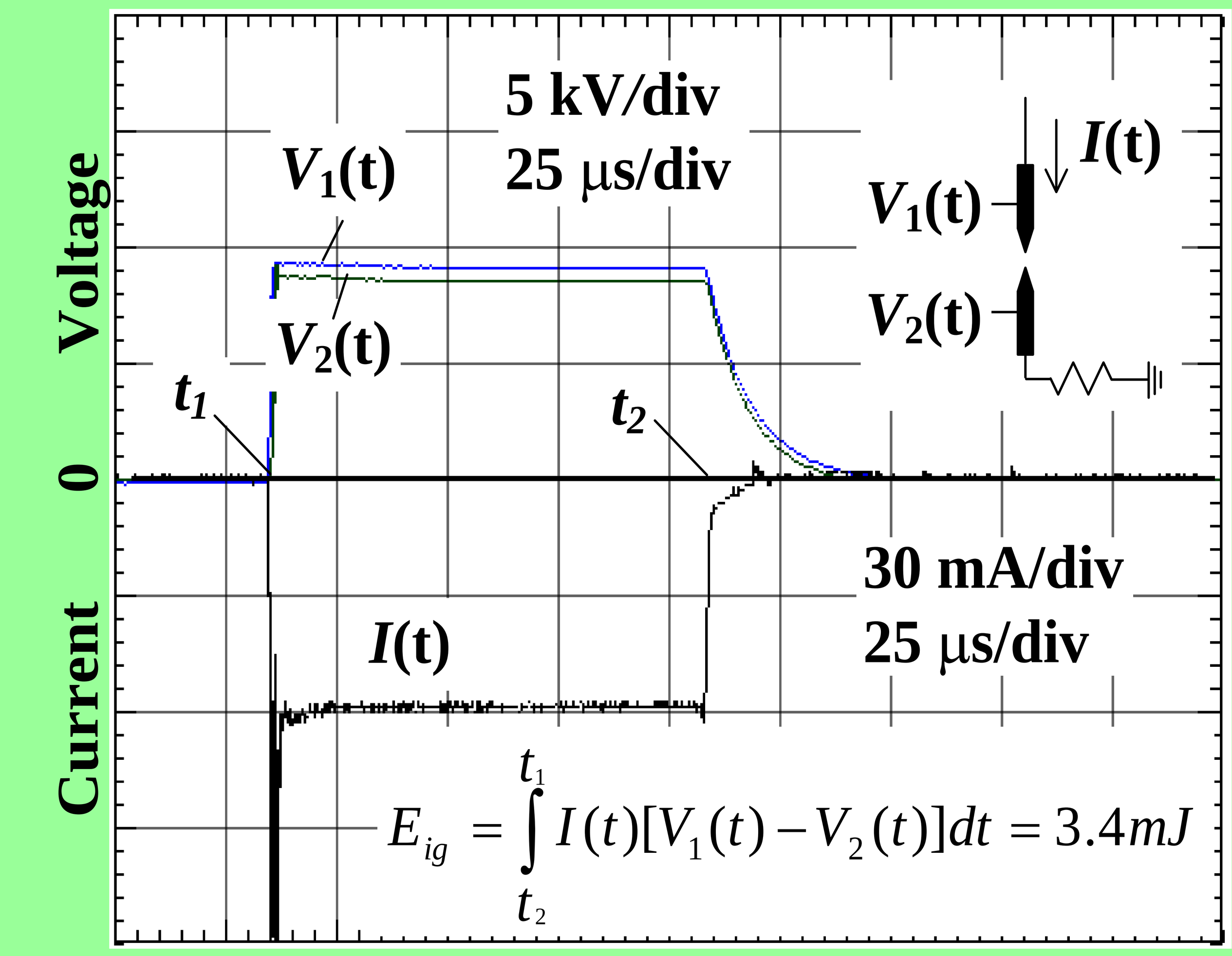
Normalized turbulent MIE data as a function of turbulent intensities at two different pressures, where MIE_L = 0.73 mJ (1atm) and 0.23 mJ (3 atm). MIE first increase modestly with increasing f and/or u', while the increase of MIE becomes much more drastically after the transition.

Determination of MIE



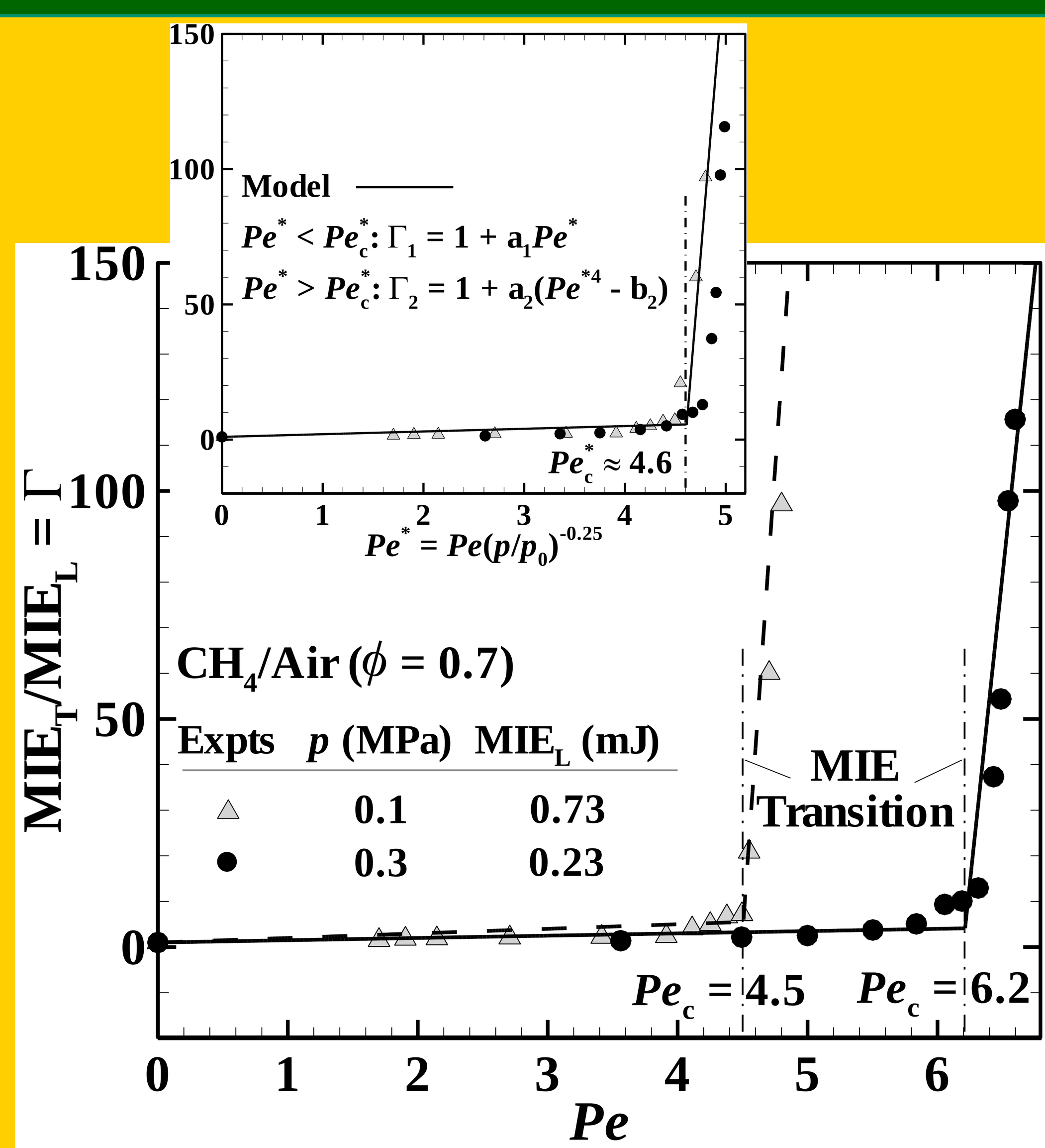
(a) The midpoint procedure. (b) The logistic regression method using the present laminar E_{ig} data measured at 3 atm.

Voltage & Current Waveforms



Typical voltage and current waveforms directly measured across the electrodes that are used to calculate E_{ig}, and using integration of the product of $I(t)[V_1(t) - V_2(t)]$ throughout the spark duration from the time t_1 to t_2.

Modeling of Turbulent MIE Transition



The inset shows that the data can be better represented by a modified $Pe^* = Pe(p/p_0)^{-1/4}$, where p_0 = 1 atm. A model is also presented to explain these results.

Concluding Remarks:

1. There is a transition on values of MIE due to different modes of combustion even at elevated pressure. At p = 0.3 MPa, the increasing slopes of $\Gamma = MIE_T/MIE_L$ curves change drastically with increasing u'/S_L from $\Gamma \sim (u'/S_L)^{0.8}$ to $\Gamma \sim (u'/S_L)^{13}$, where the critical $u'/S_L \approx 60$ for the transition. It is found that values of Γ at 3 atm are much smaller than that at 1 atm at any given values of u'/S_L.
2. These MIE data can be nicely merged together when a modified reaction zone Péclet number, $Pe^* = Pe(p/p_0)^{-1/4}$, is used to correct the effect of elevated pressure. A model is proposed to explain such MIE transition at elevated pressure.
3. For the pre-transition when $Pe^* < Pe^*_c \approx 4.6$, $\Gamma_1 = 1 + Pe^*$, while $\Gamma_2 = 1 + (Pe^{*4} - 443)$ for the post-transition when $Pe^* > Pe^*_c$. The agreement between the model predication and the experimental data is good.