Measurement of critical conditions of extinction in a counter-flow burner

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Introduction

- Fundamental experimental data on extinction of any hydrocarbon fuel acts as an important validation target for its kinetic mechanism.
- Apparatus and procedure for the measurement of the critical conditions of extinction for any gaseous fuel are described below in a systematic manner.

Prevention is Better than Cure!!

- Follow the basic safety instructions (wearing lab coat, lab shoes, use of fire extinguisher, fire alarm etc).
- Always remember to cut off the supply of fuel or oxygen or both in case of any fire hazard.
- Ensure all the connections in the setup are leakproof especially when working with gaseous substances.
- Always ensure compatibility between the gaseous substances and materials used for their supply system.

Counter-flow Burner Apparatus

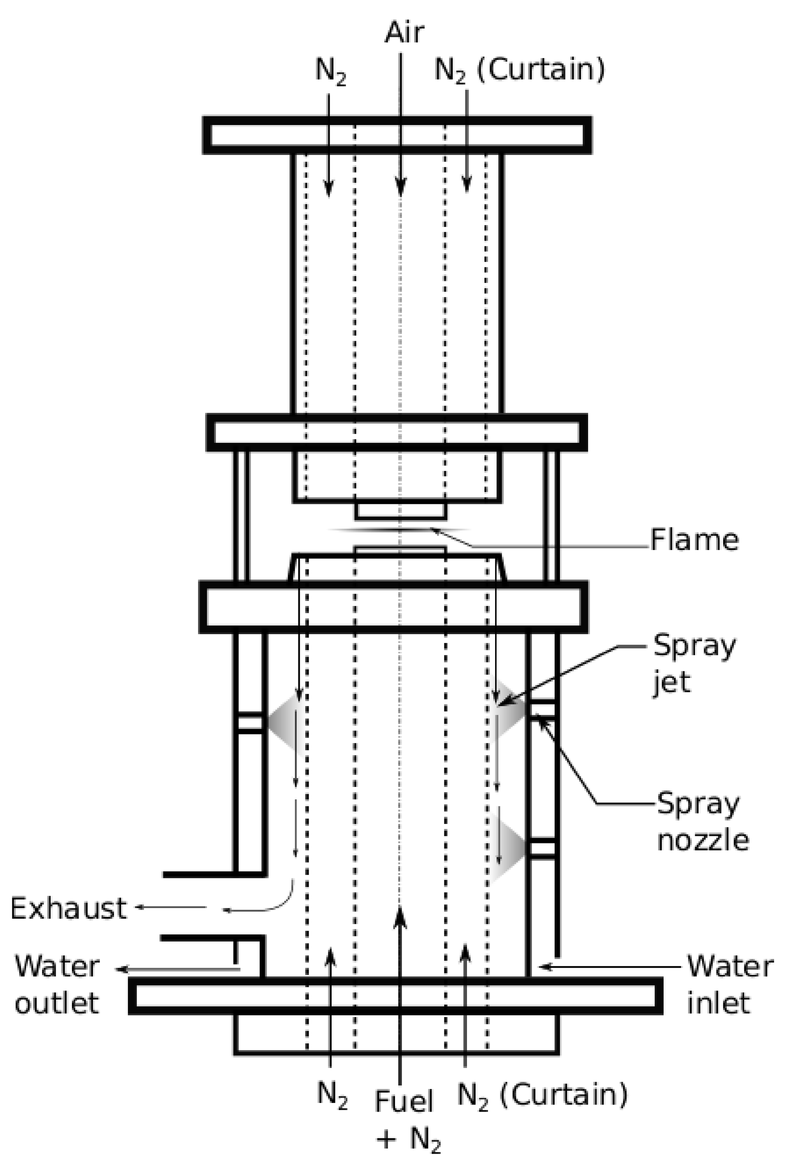

Figure 1: Schematic of the counter-flow burner setup.

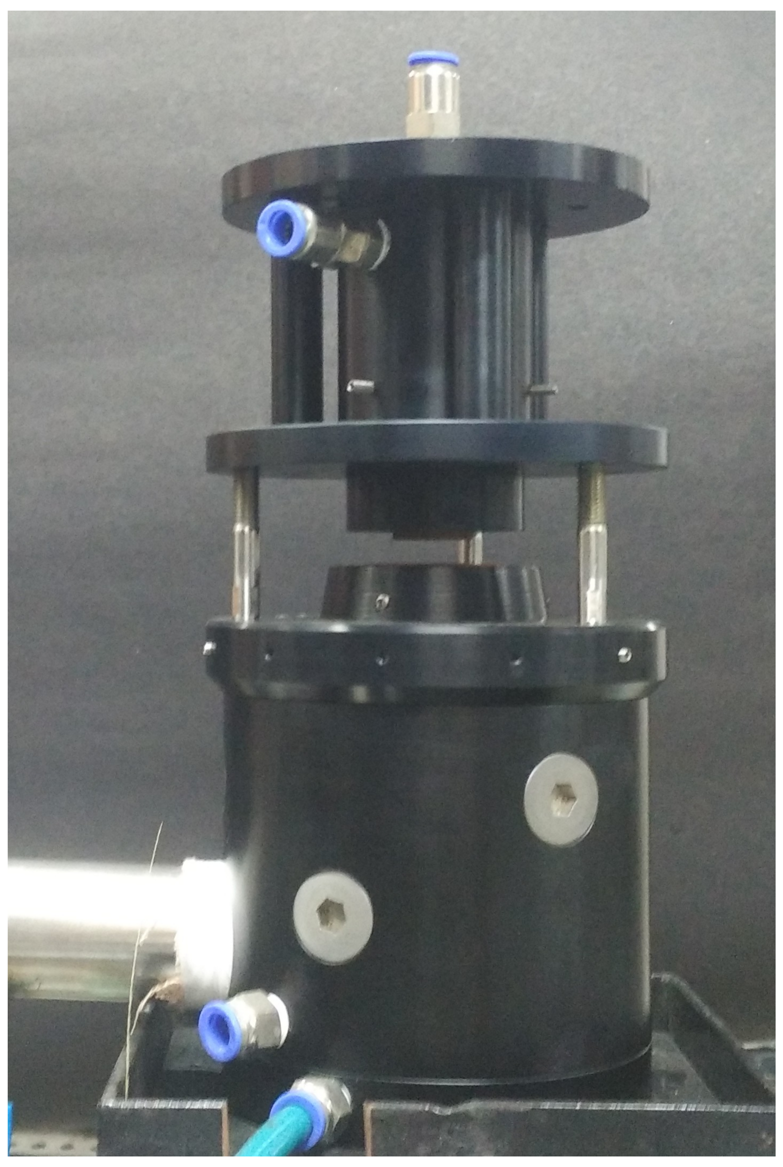

Figure 2: Actual counter-flow burner setup.

- Fuel (bottom) and oxidizer (top) ducts are kept co-axially opposing each other as shown in Fig. 1.
- Fuel and oxidizer ducts are surrounded by two and one concentric annular ducts respectively.
- Nitrogen is supplied through the inner annular gap on the fuel side and the annular duct on the oxidizer side to minimize the effect of ambient interference.
- The outer annular duct on the fuel side is connected to an exhaust system using a flexible aluminium hose, which facilitates suction of the hot product gases.
- The outer walls of this duct are provided with water spray nozzles (type BETE PJ15) to cool the hot product gases and thereby prevent their autoignition in the exhaust duct.
- Water is supplied to the spray nozzles through a mini centrifugal pump (TULLU AC-30).
- At the exit of the fuel and oxidizer ducts, three layers of stainless steel wire meshes (200×200 meshes/inch) are mounted to ensure plug-flow boundary condition.
- The meshes are mounted using four stainless steel rings of 1 mm thickness.
- Proper alignment of the meshes is very important to achieve a flat flame.
- Fuel and dilutant nitrogen are mixed homogeneously in a cylindrical mixing chamber.
- The top burner is mounted and aligned with the bottom burner with the help of adjustable screws.
- The desired distance between the duct exits is maintained by adjusting the screws manually.
- To ensure stability of the flame, the exhaust system should provide sufficient power for the complete suction of the combustion products.

Very Important: Never perform any flame experiments alone. Perform the experiments in the presence of your labmates/advisors/mentors.

Experimental Procedure

- Firstly, perform a leak test for all the connections using air.
- Handle all the cylinders epsecially the fuel cylinder with care and preferrably keep it away from the setup.
- Turn on all the cylinders and the air supply system. Make sure all the supply lines are turned off.
- Before starting the experiments, turn on the water cooling system.
- The fuel is gradually allowed to flow through the fuel duct and is ignited using a pilot flame.
- The exhaust system is turned on and the flame is allowed to stabilize as shown in Fig. 3.

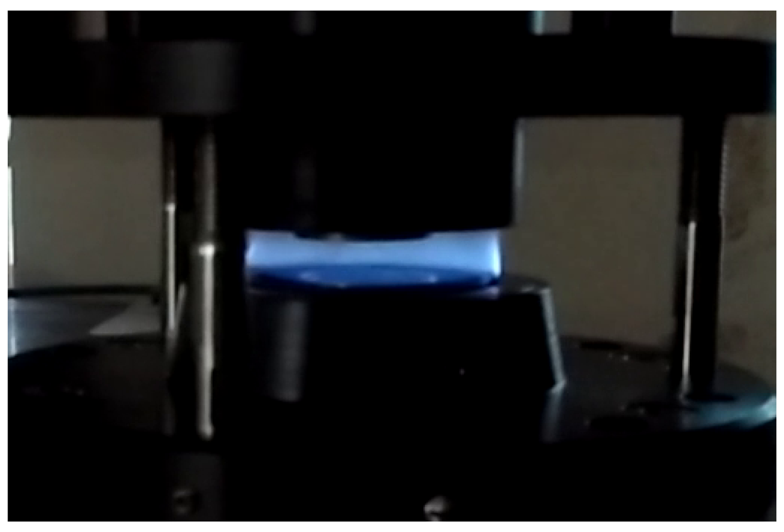

Figure 3:

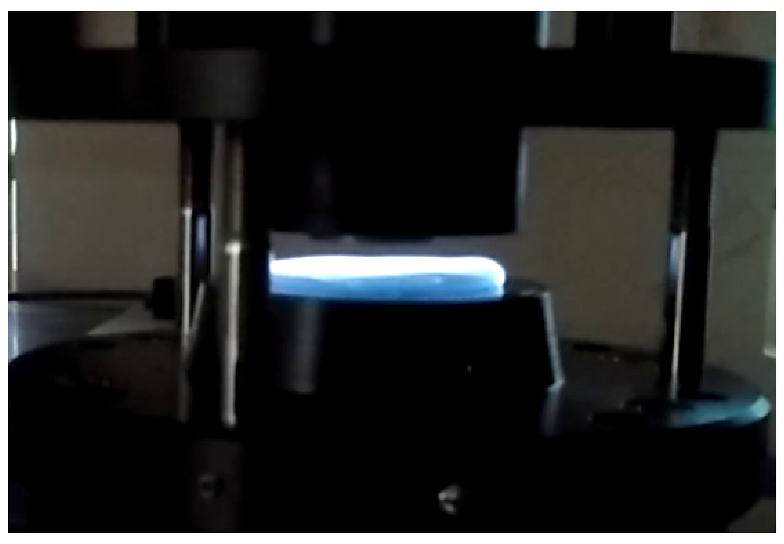

Figure 4:

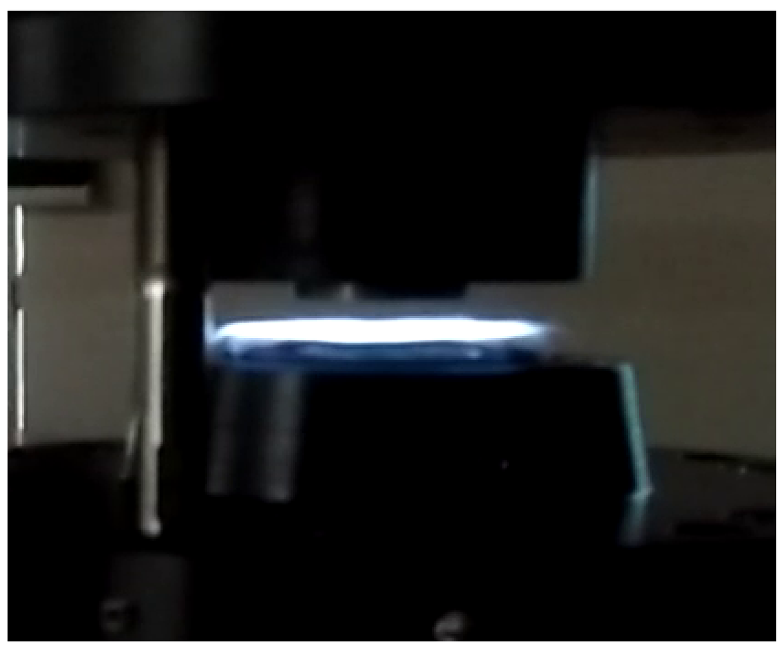

Figure 5:

- Air is allowed to enter through the oxidizer duct to establish a flat flame as shown in Fig. 4.
- Curtain flow of nitrogen is turned on from the top and the bottom ducts to isolate the flame from the ambient effects and the corresponding flame is shown in Fig. 5.
- Thereafter, the fuel is gradually diluted with nitrogen in the mixing chamber until the flame extinguishes.
- The phenomenon of extinction is observed visually through several trials.
- The corresponding flowrates of fuel, dilutant nitrogen and air at extinction are recorded.
- As soon as the flame extinguishes, the fuel and oxidizer supply is cut off immediately to avoid accumulation in the exhaust system.
- The setup is then allowed to cool upto the ambient temperature before starting the next experimental trial.
- The above procedure is repeated to obtain the extinction strain rates for different fuel and dilutant nitrogen flow rates.
- While performing experiments, the momenta of the counterflowing reactant streams at the boundaries are kept almost equal to each other.
- This condition ensures that the stagnation plane formed by the two streams is approximately at the middle of the region between the two ducts.

Calculating the Strain Rate at Extinction

- In the region between the stagnation plane and the oxidizer duct, the characteristic strain rate, $\mathbf{a_2}$, defined as the normal gradient of the normal component of the flow velocity, evaluated at the stagnation plane, is given by:

$$\mathbf{a_2} = \frac{2|\mathbf{V_2}|}{\mathbf{L}}\left(1 + \frac{|\mathbf{V_1}|\sqrt{\rho_1}}{|\mathbf{V_2}|\sqrt{\rho_2}}\right)$$

  Here, subscripts 1 and 2 denote the fuel and oxidizer sides, respectively, $\mathbf{L}$ denotes the distance between the two ducts, $\mathbf{V}$ the flow velocity normal to the stagnation plane and ρ represents the density. The average velocities of the reactants are estimated as the ratio of corresponding volumetric flow rates to the cross-section area of corresponding ducts.
- Using the recorded values of flowrates of fuel, dilutant nitrogen, and oxygen, the strain rate at extinction can be calculated using above equation.
- Sample extinction results for dimethyl ether using this setup are published in: R.S. Khare et al./ Combustion and Flame 196 (2018) 116–128.

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