Pressure Effects on the Turbulent Flame Speeds of Syngas Mixtures

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Introduction

Motivation

Ability to operate lean, premixed gas turbines safely and reliably with synthetic gas (syngas) fuels derived from biomass

- Lean, premixed combustion reduces the emission of harmful pollutants such as nitrous oxides (NO_x).

Figure 1: Tampa Electric Integrated Gasification Combined Cycle Plant (*1*)

Why Syngas?

Syngas can be used to reduce the global carbon footprint.

- High hydrogen content fuel (2).
- Cleaner and more efficient than burning solid biofuels.
- Derived from renewable resources.

Issues

1. Syngas composition is highly variable.
   - Depends on fuel source and processing technique.
   - Primarily composed of H_2 and CO (2).
2. Burning properties of syngas are not well understood.
   - Especially at the high pressures and turbulence intensities experienced in gas turbine combustors.

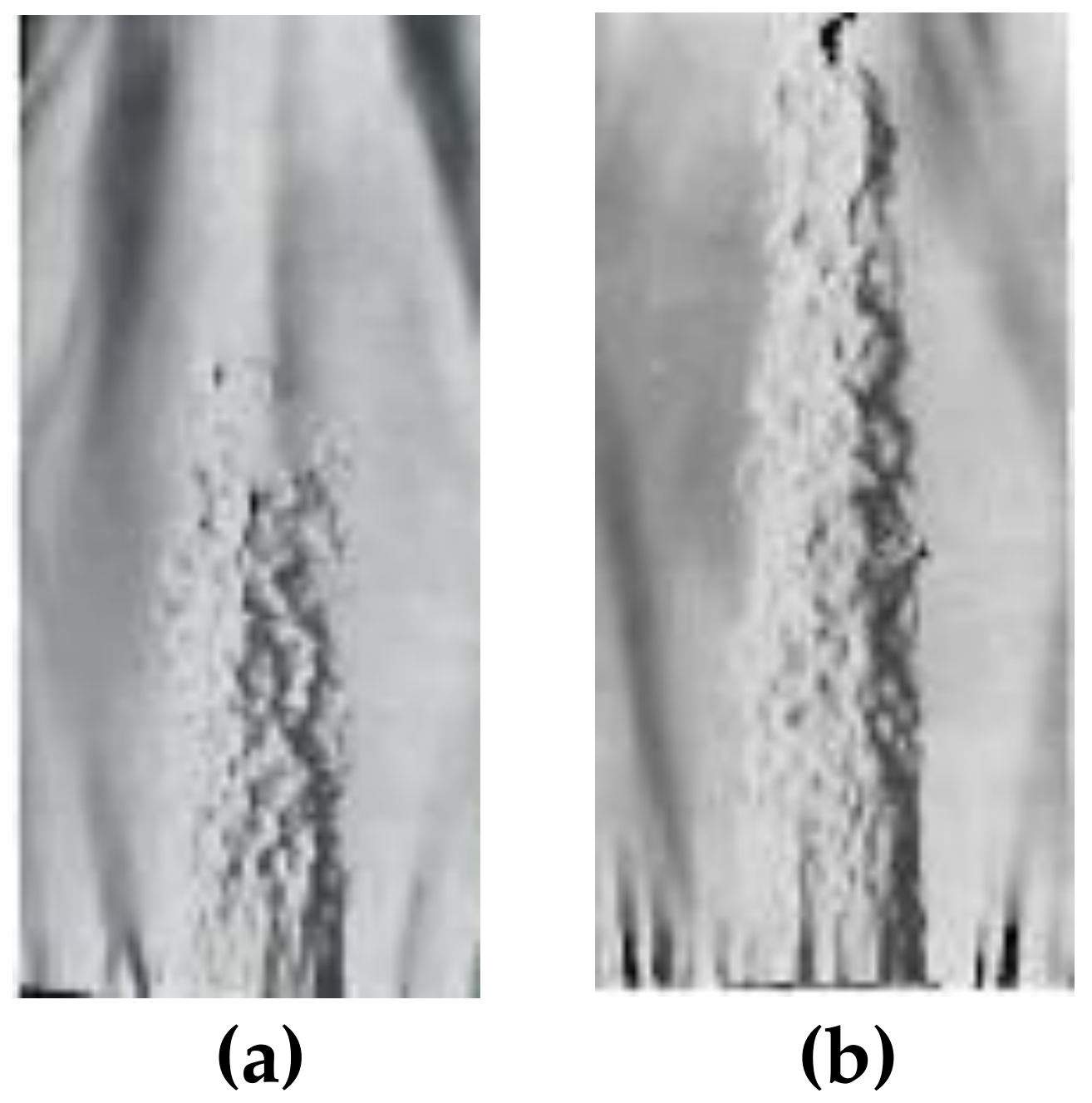
Turbulent Flame Speed

Measures average rate reactants are consumed by the turbulent flame front per unit area:

$$S_T = \frac{\dot{m}_R}{\rho_R \bar{A}_{<c>}}$$

Traditional correlations of the form $S_T = S_L \cdot f(u'/S_L)$ do not capture important characteristics of S_T (3).

- Also affected by fuel composition



(a) (b)

Figure 1: H_2/air flames with $S_{L,0}$ = 2 m/s, *Re* = 20,000, and (a) φ = 1.0, (b) φ = 3.57 (*4*)

Objectives

1. **Obtain turbulent flame speed data of syngas fuel blends at gas turbine conditions over a range of conditions.**
2. **Develop physics-based scalings to predict turbulent flame speed dependencies across a broad fuel space.**

Methods

Burner

Piloted Bunsen flame.

Turbulence Generator

Ability to vary turbulence intensity over a wide range (*5*).

High Pressure Facility

Tested to 20 atm.

- Optically accessible.

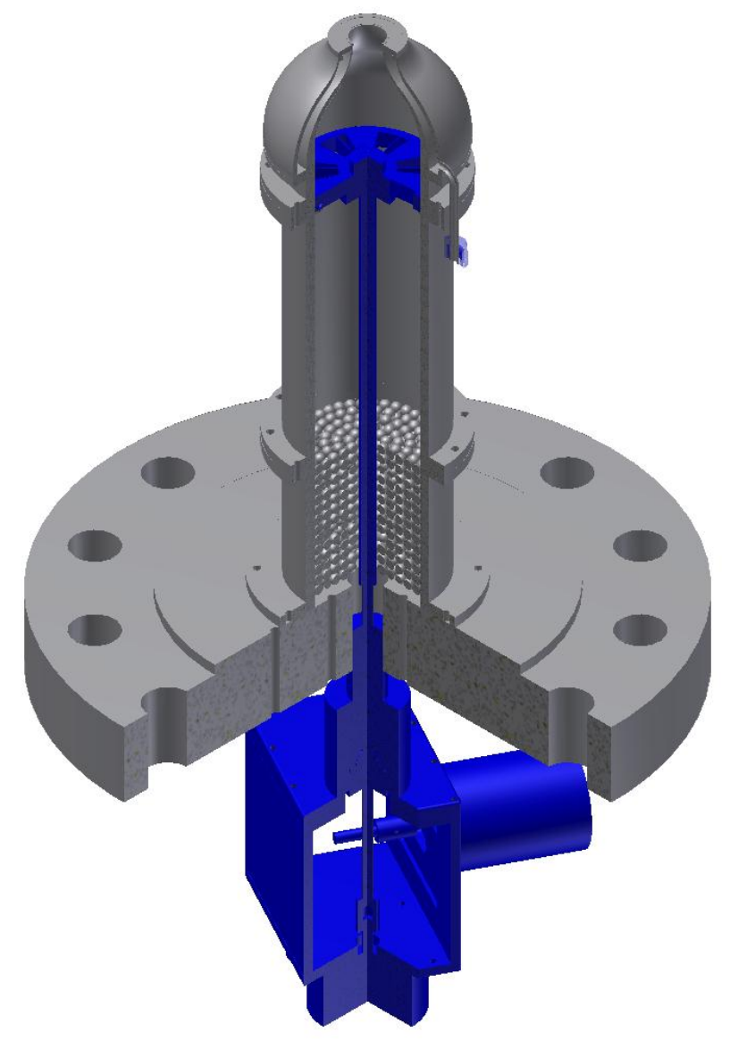


Figure 2: Experimental Facility

Results

Conditions

- Constant $S_{L,0}$
- Pressures: 1-10 atm
- Velocities: 20-50 m/s
- H_2/CO ratios: 30/70-90/10

Table 1: Legend of conditions

	Constant $S_{L,0}$			
U_0 (m/s)	20, 30, 50			
H_2 (%)	30	50	70	90
Symbol	o	◁	▷	◇
ϕ, 1 atm	0.61	0.55	0.51	0.48
ϕ, 5 atm	0.75	0.68	0.63	0.59
ϕ, 10 atm		0.75		
$S_{L,0}$ (m/s)	0.34			

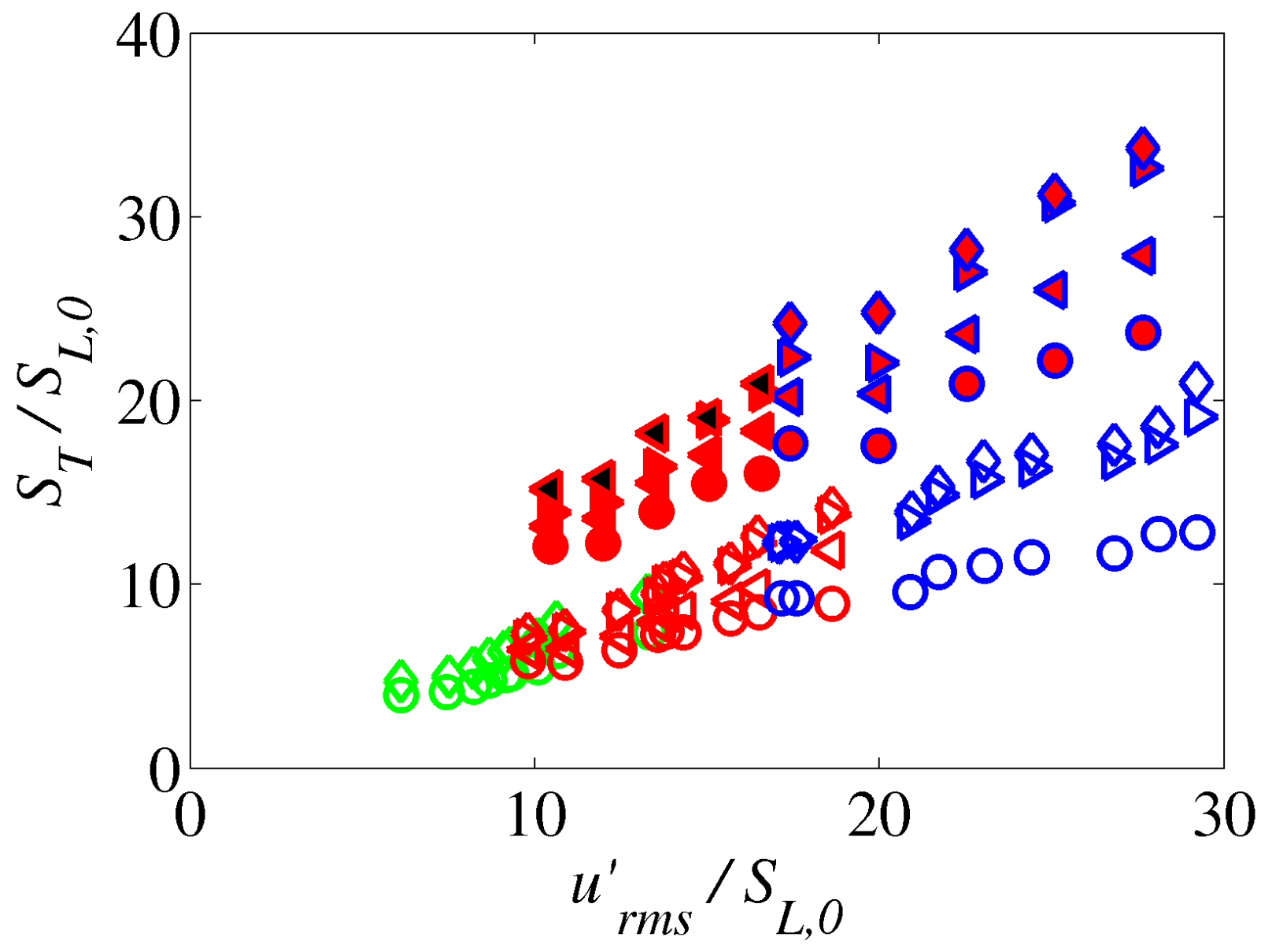


Figure 3: S_T as a function of u'_{rms} normalized by $S_{L,0}$ at the conditions shown in Table 1

Observations

1. "Fuel effect" present at all conditions
   - Increase in S_T with H_2 content at fixed $S_{L,0}$ and u'_{rms}
2. S_T increases with pressure
   - Factor of 2 increase from 1-5 atm
   - Factor of 2.2 increase from 1-10 atm

Analysis

Flame Stretch

Combination of flame curvature and fluid dynamic strain.

- Alters flame structure and the laminar flame speed, S_L.
  - Imbalance of diffusion of heat and reactants near the flame front.

Flame Speed Scaling

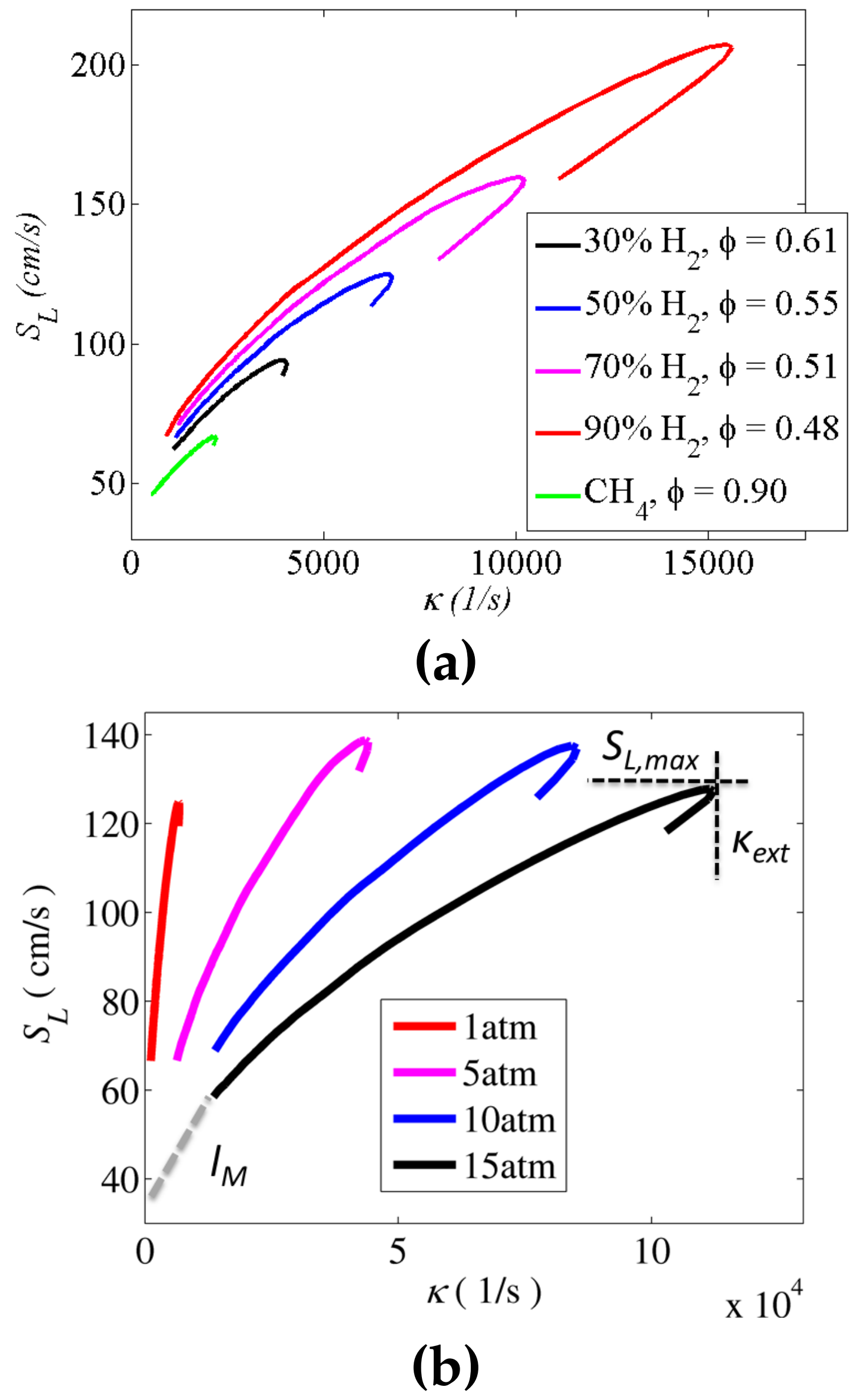
Leading points are points on the turbulent flame front that propagate out farthest into the reactants. One hypothesis is that the dynamics of leading points control the turbulent flame speed (*6*).

- Stretch effects cause S_L at the leading points to increase.
- Steady state value is $S_{L,max}$
- Leads to the following scaling relation:

$$\frac{S_T}{S_{L,\max}} = 1 + \frac{u'}{S_{L,\max}}$$

Flame speed data normalized with $S_{L,max}$ collapse well at a fixed pressure.

- Analyzing difference between pressures in terms of a time scale analysis.



(a)

(b)

Figure 4: Effect of strain rate on S_L for different (a) mixtures and (b) pressures (H_2/CO = 50/50)

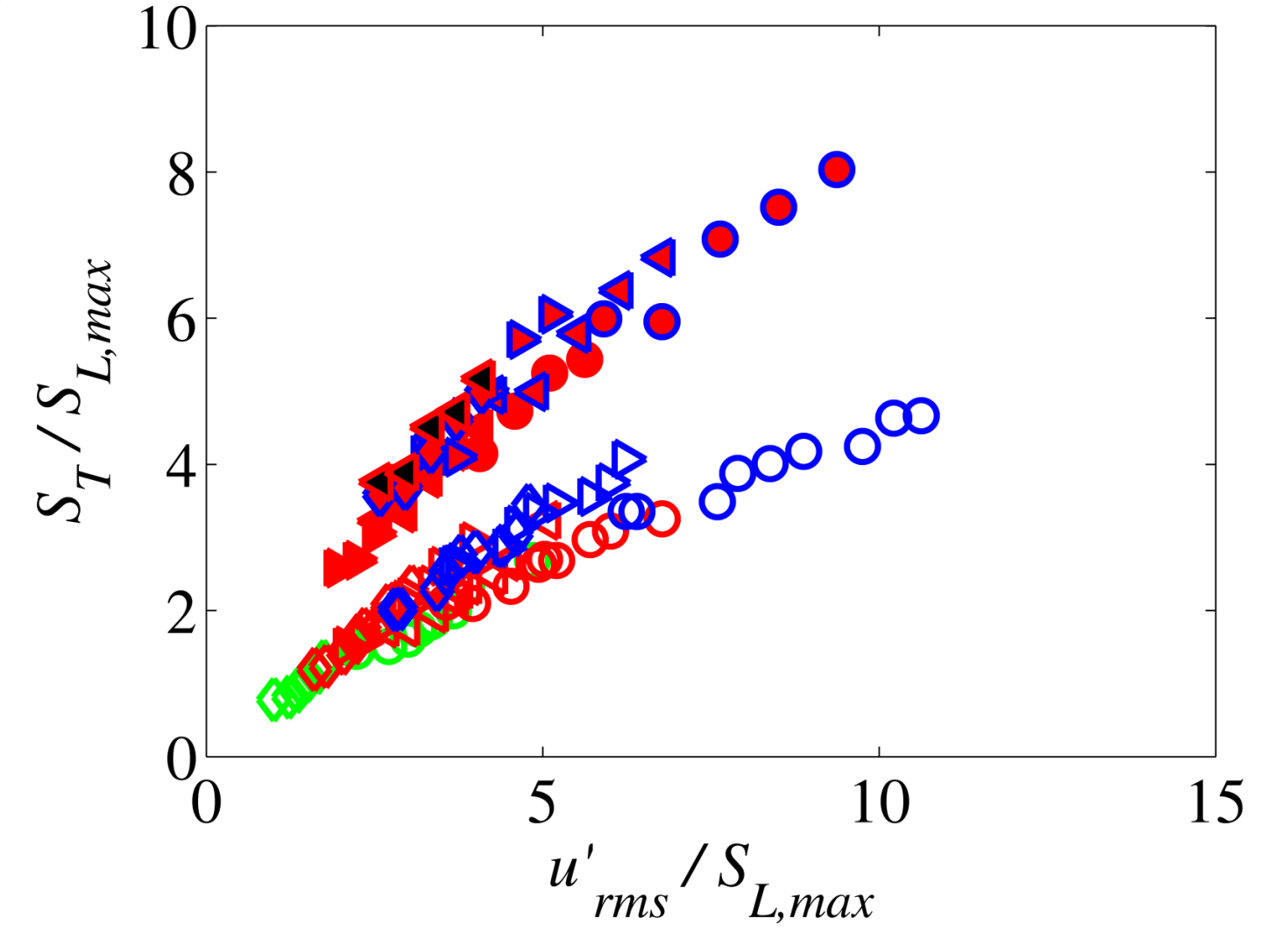


Figure 5: S_T as a function of u'_{rms} normalized by $S_{L,max}$

Conclusions

1. "Fuel effect" persists for all velocities and pressures.
2. Turbulent flame speeds increase with pressure.
3. Data can be normalized with a leading points scaling law.

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