

# Gas Turbine Industrial Fellowship Program 2006

## Predicting Lean Blowout Using the Damkohler Number

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## Need

A microturbine that adapts to surrounding conditions, avoiding premixed lean blowout by predicting when to stage fuel and engage the pilot fuel.

## Objectives

Create a correlation that accurately predicts Damkohler number based on measured temperatures, measured pressures, and the predetermined lower heating value of the fuel.



Ingersoll Rand MT70 Microturbine

*Damkohler number has been shown to accurately predict premixed lean blowout. Damkohler number is defined by Noble<sup>[1]</sup> et al. as the ratio of the residence and chemical kinetic times,*

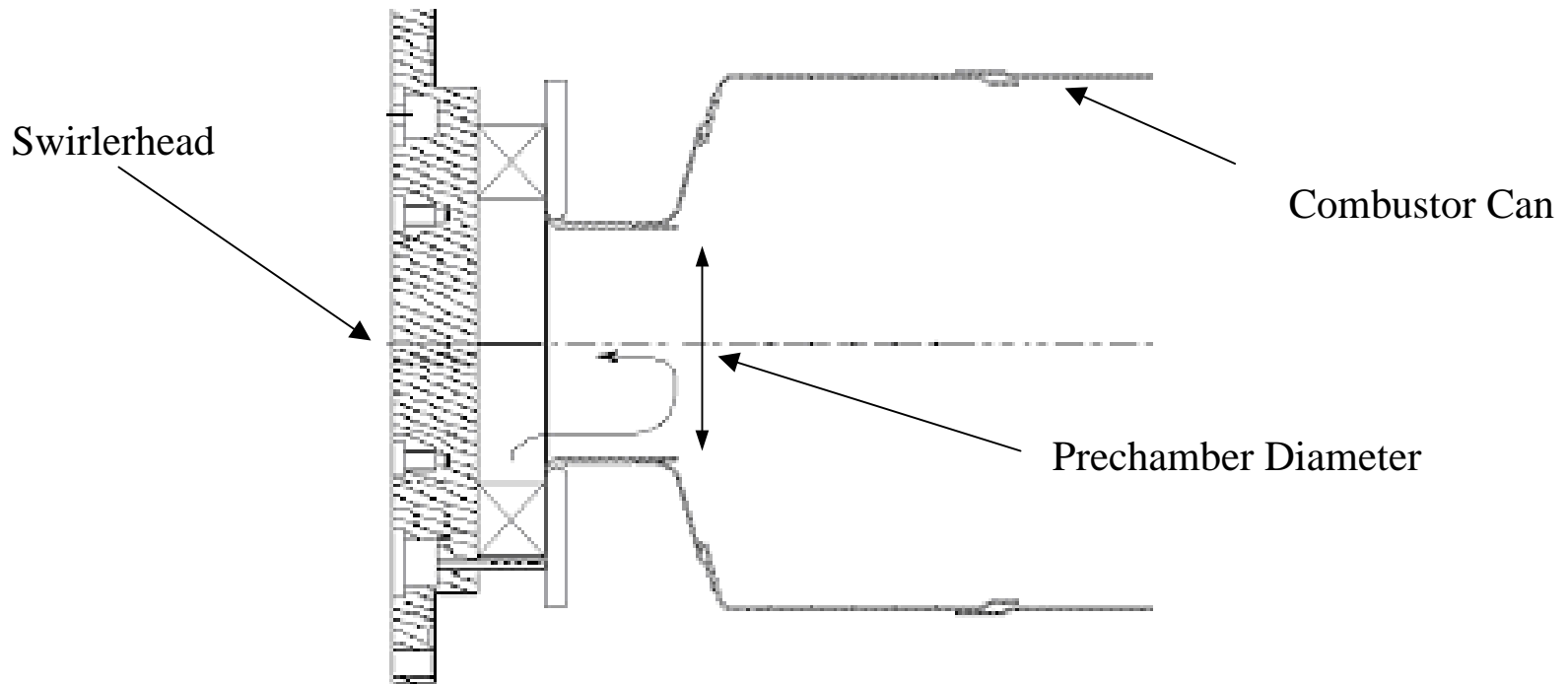
$$Da = \frac{\tau_{res}}{\tau_{chem}} = \frac{S_L^2 d}{\alpha U_{ref}}$$

*In this study the Damkohler was modified to be*

$$Da = \frac{\tau_{res}}{\tau_{chem}} = \frac{S_L d}{f_T U_{ref}}$$

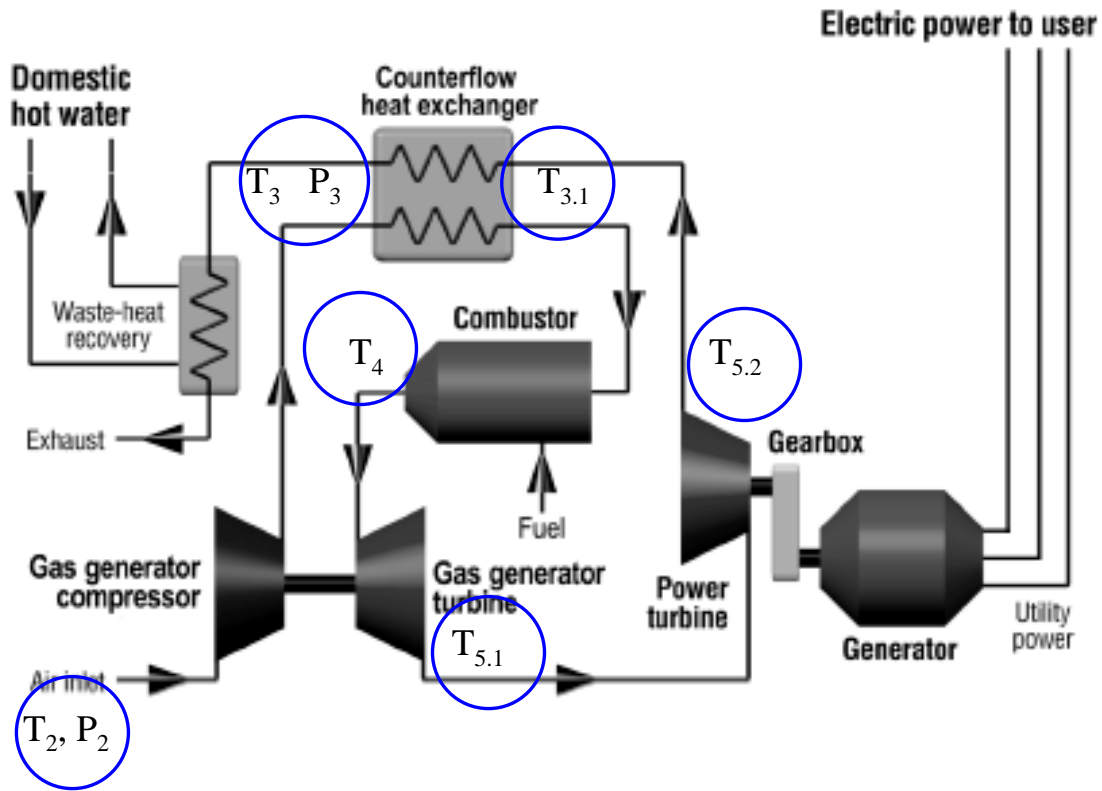
*where  $S_L$  is the flame speed,  $d$  is a characteristic length,  $f_T$  is the flame thickness, and  $U_{ref}$  is a characteristic velocity.*

*In this study,  $d$  is defined as 1/2 the radius of the Prechamber*



Sketch of a combustor can and prechamber

# Cycle Diagram



MT70 Cycle Diagram<sup>[2]</sup>

# Characteristics Velocity, $U_{ref}$

The characteristic velocity is the velocity of air entering the primary zone of the combustor. The equation found on the right was used to calculate this velocity. In this equation,  $\rho_{3.1}$  (the density of the air at the combustor inlet) is not a measured value. Consequently, the following steps were taken to estimate it.

$$U_{ref} = \frac{\dot{m}_{PZ}}{\rho_{3.1} A_{PZ}}$$

$$T_{3,s} = T_2 \left( \frac{P_3}{P_2} \right)^{k-1/k} \quad \leftarrow$$

1. Calculate the isentropic temperature rise across the compressor using measured pressures

2. Using the equation for the compressor efficiency (removed for proprietary reasons), estimate the actual temperature at the exit of the compressor using the equation for compressor efficiency.

$$\longrightarrow T_3 = \frac{T_{3,s} - T_2}{\eta_c} + T_2$$

$$T_{3.1} = T_3 + \varepsilon(T_{5.2} - T_3) \quad \leftarrow$$

3. Using the efficiency of the recuperator, calculate the inlet temperature of the combustor.

4. Solve for the unknown density using the Ideal-gas approximation. The velocity can then be directly solved.

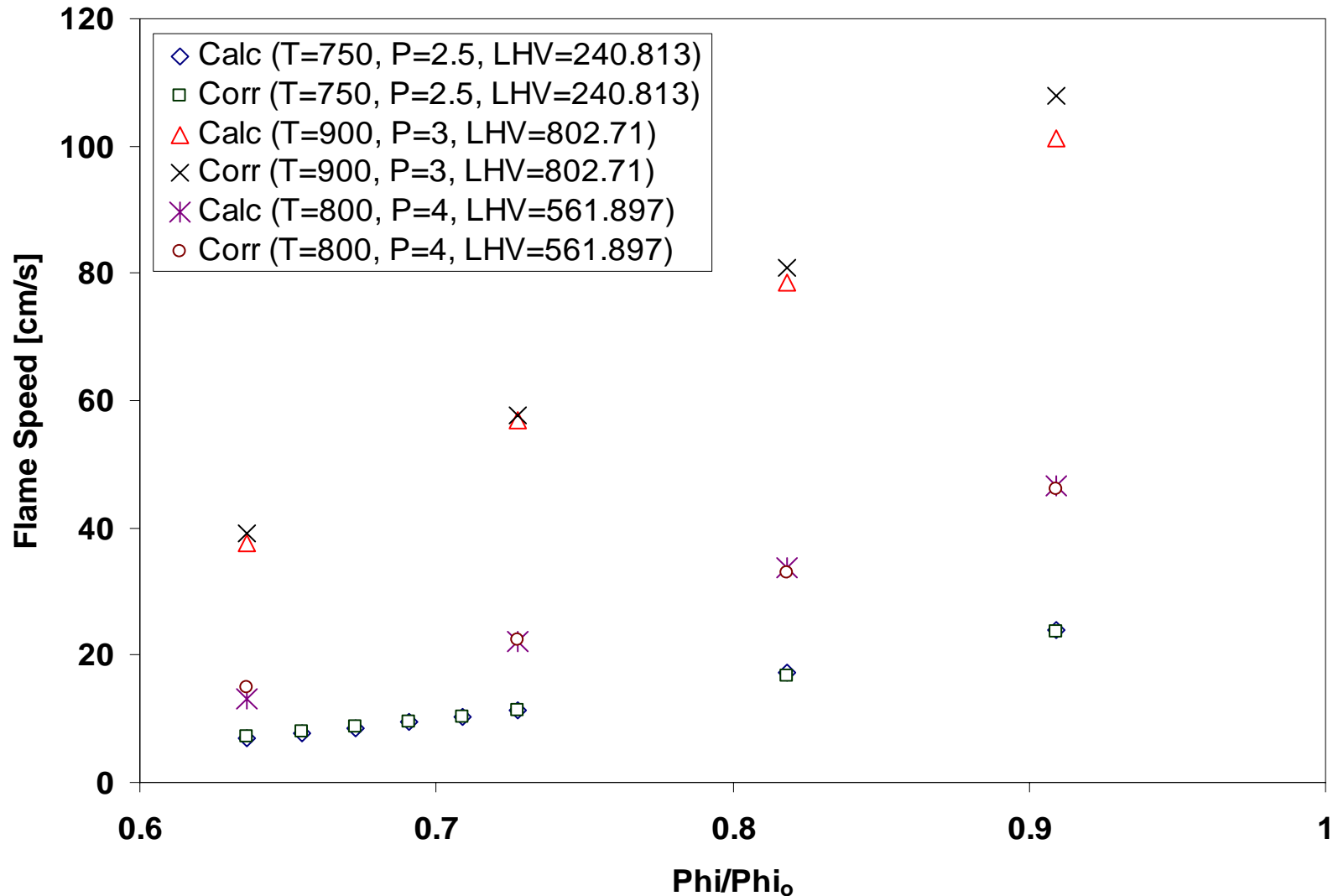
$$\longrightarrow \rho_{3.1} = \frac{P_3}{R_{Air} T_{3.1}}$$

- Predicted flame speed using Sandia Lab's PREMIX<sup>[3]</sup> code along with CHEMKIN<sup>[4]</sup> and TRANSPORT<sup>[5]</sup>. The kinetic model used in the prediction was from GRI-Mech 2.11<sup>[6]</sup>.
- The kinetic model consisted of 49 species and 279 reactions and was used to predict the combustion characteristics of methane.
- The predictions were made over a range of temperatures (700-900 K), pressures (2.5-4 atm), and lower heating values (240-800 kJ/mol).
- Based on the predictions the form of the correlation was chosen (removed for proprietary reasons)

$$S_L = f(\phi, T, LHV, P)$$

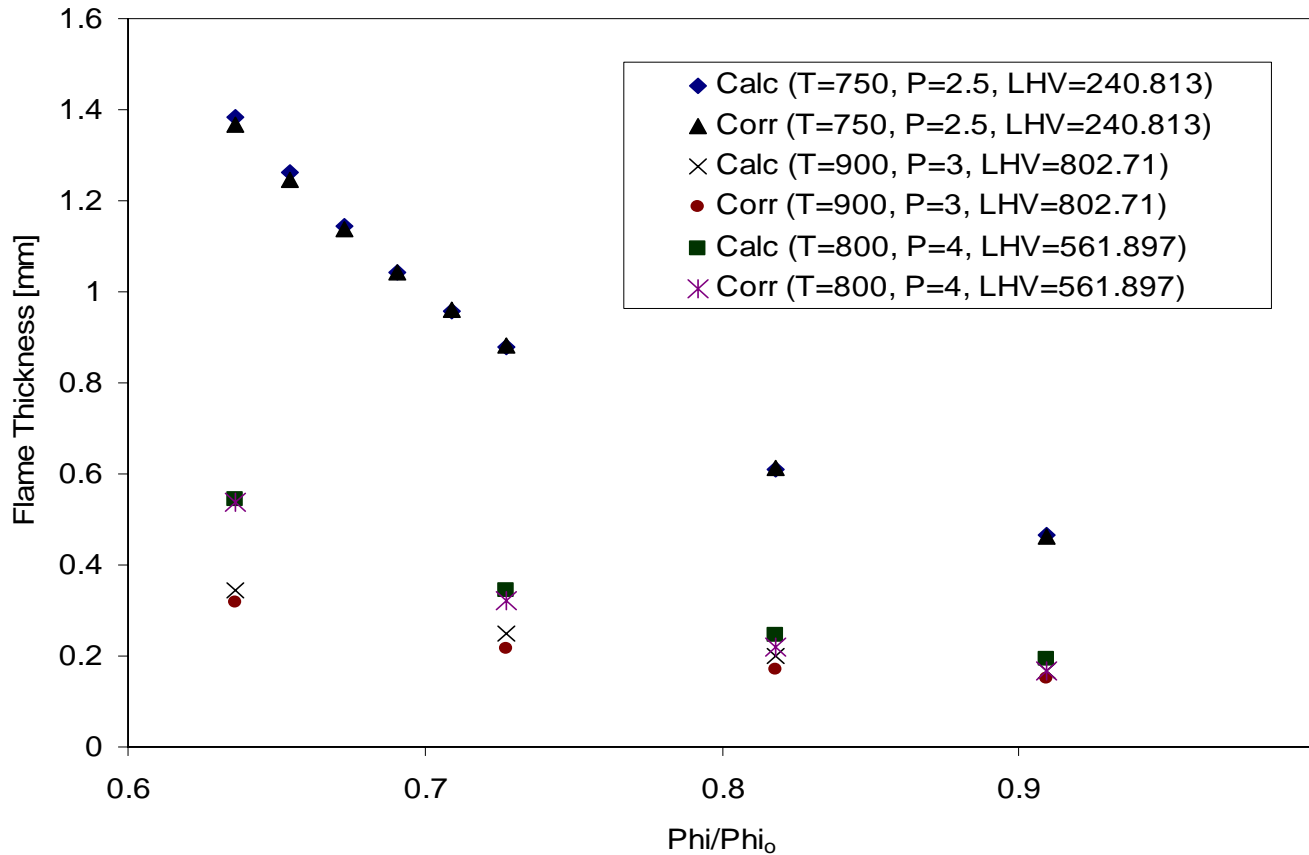
- The regression tool in Excel was used to create an equation that depended entirely on temperature, pressure, lower heating value of the fuel, and the equivalence ratio in the primary zone.

# Flame Speed Correlation Results



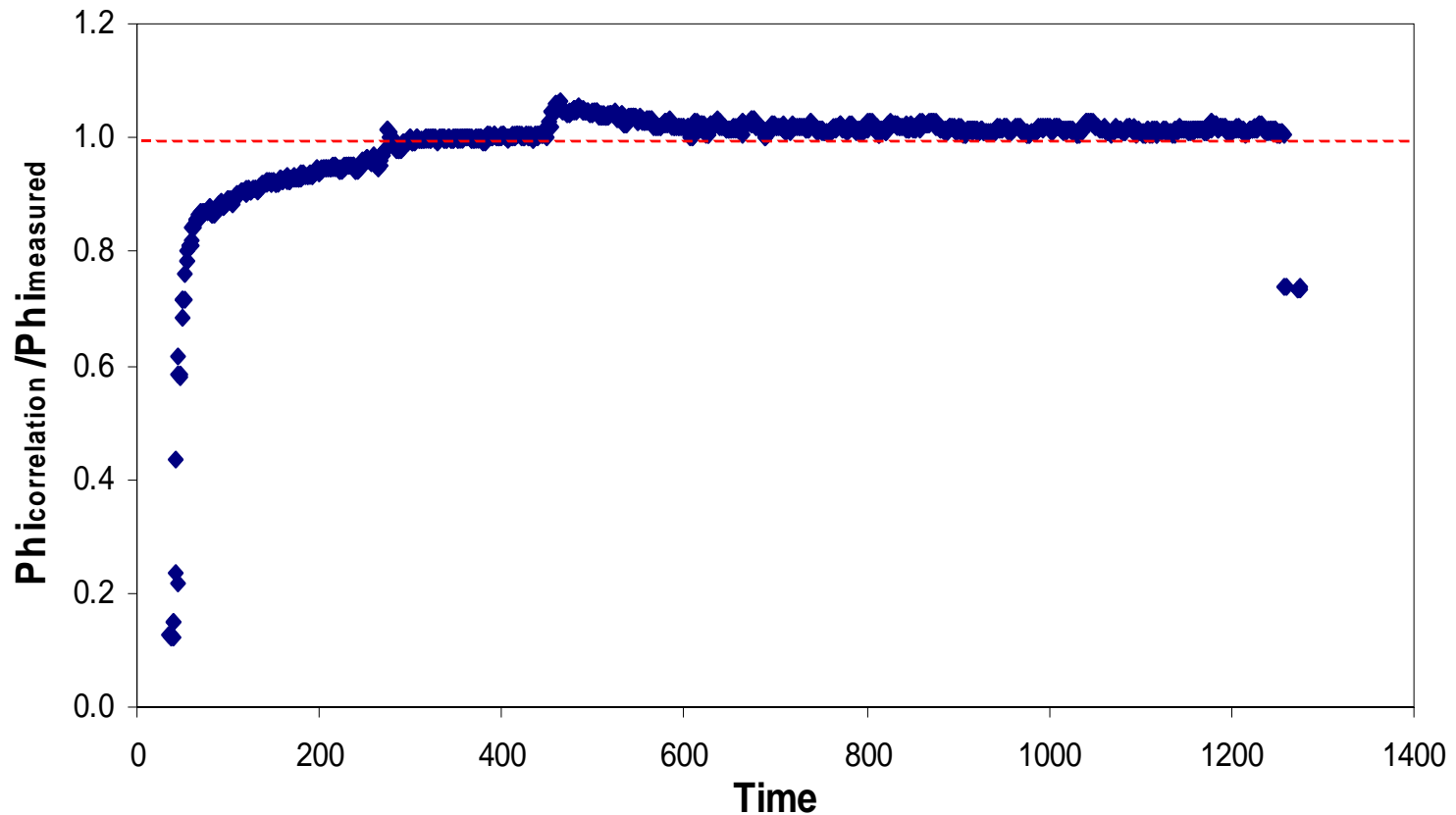
Used a similar methodology for the flame thickness correlation. The form of the solution was chosen to be (removed for proprietary reasons)

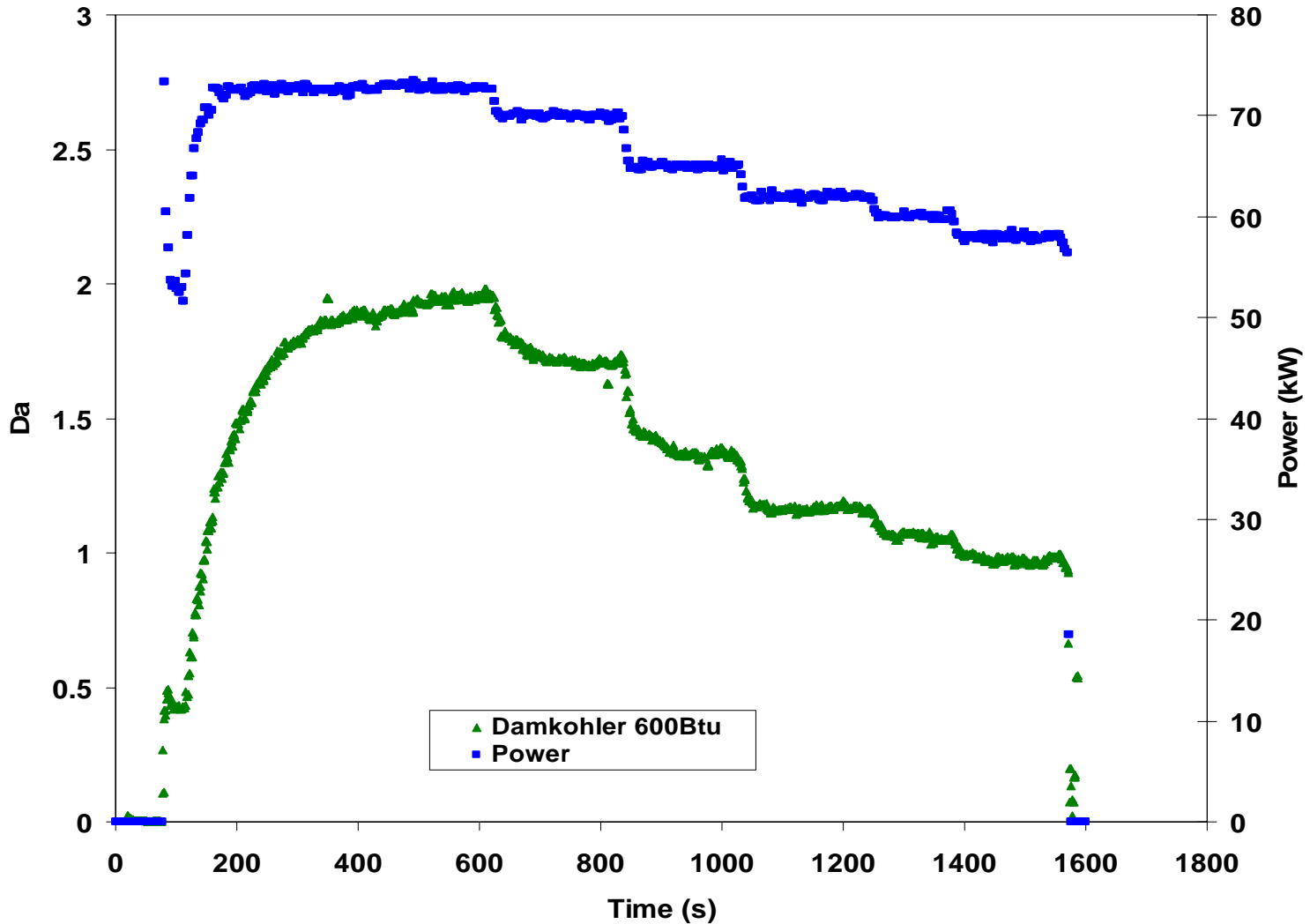
$$f_T = f(\phi, T, LHV, P)$$

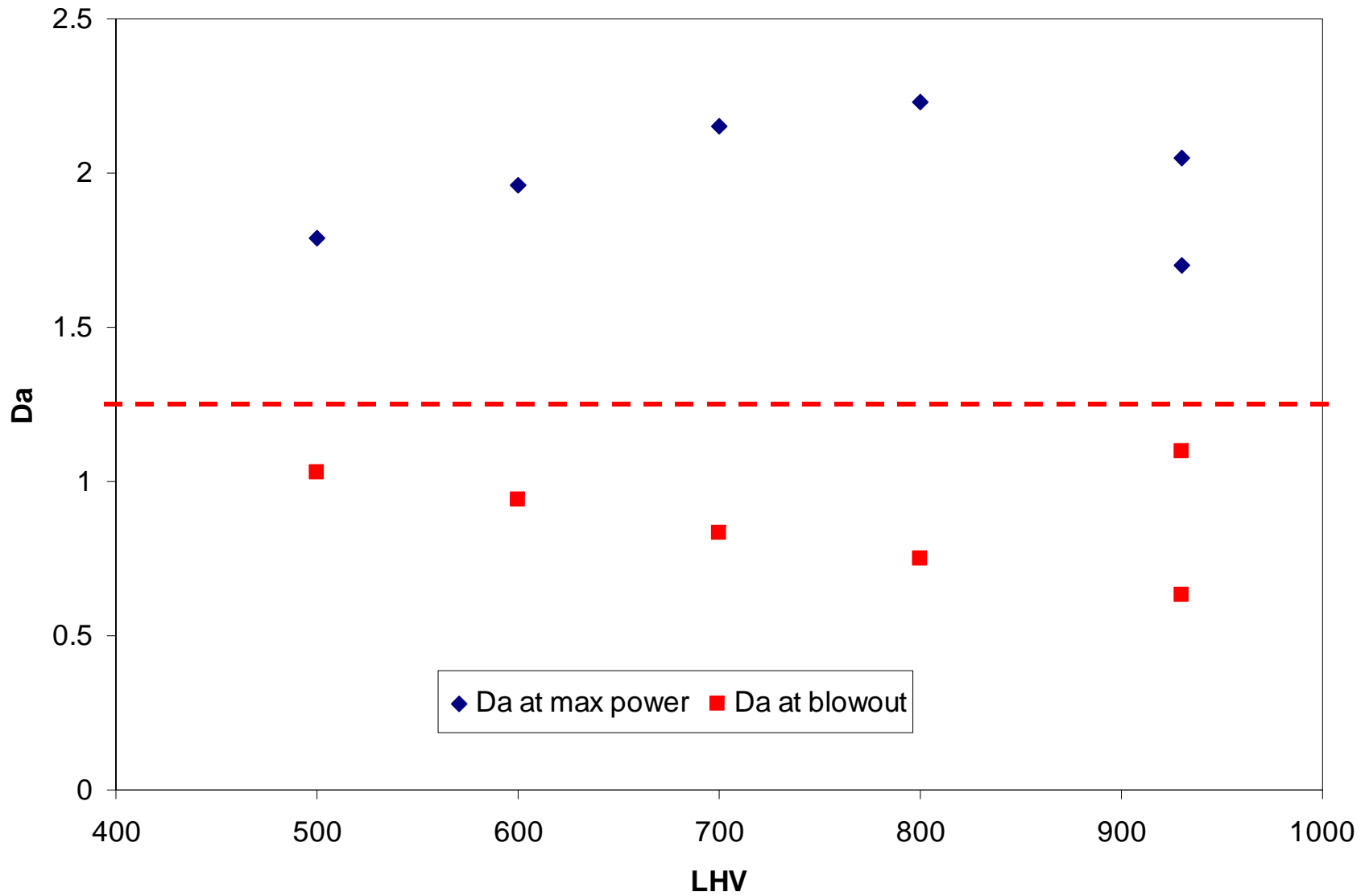


## Correlation for Equivalence Ratio

- A correlation for equivalence ratio was also created based solely on temperatures and the lower heating value of the fuel. The procedure has been removed for proprietary reasons.







- Correlations for flame speed, flame thickness, and equivalence ratio accurately predict the calculated values
- Correlation for the Damkohler number tracks the power of the microturbine
- Damkohler consistently predicts premixed lean blowout near unity for the selected characteristic diameter
- Correlations are accurate over the desired range of temperatures, pressures, and lower heating values

<sup>1</sup>Noble, D. R., Zhang, Q., Shareef, A., Tootle, J., Meyers, A., Lieuwen, T.,  
“Syngas Mixture Composition Effects Upon Flashback and Blowout,” *Proceedings of ASME Turbo Expo 2006: Power for Land, Sea, and Air*, GT2006-90470.

<sup>2</sup>Ingersoll Rand Power Works, “70LM Microturbine: Operating Manual,” pg. 25.

<sup>3</sup>Kee, R.J., Grcar, J.F., Smooke, M.D., and Miller, J.A., Sandia Report SAND 85-8240, Sandia National Laboratories, 1985.

<sup>4</sup>Kee, R.J., Rupley, F.M., and Miller, J.A., Sandia Report SAND 89-8009B, Sandia National Laboratories, 1989.

<sup>5</sup>Kee, R.J., Warnatz, J., and Miller, J.A., Sandia Report SAND 83-8209, Sandia National Laboratories, 1983.

<sup>6</sup> Smith, G.P., Golden, D.M., Frenklach, M., Moriarty, N.W., Eiteneer, B., Goldenberg, M., Bowman, C.T., Hanson, R.K., Song, S., Gardiner, W.C., Jr., Lissianski, V.V., and Qin, Z, [http://www.me.berkeley.edu/gri\\_mech/](http://www.me.berkeley.edu/gri_mech/).