CHARACTERISTIC TIME MODEL CORRELATION OF
NO₂ EMISSIONS FROM LEAN PREMIXED COMBUSTORS

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ABSTRACT

The semi-empirical characteristic time model (CTM) has been used previously to correlate and predict emissions data from conventional diffusion flame, gas turbine combustors. The form of the model equation was derived for NOₓ emissions from laboratory flameholders and then extended to conventional gas turbine combustors. The model relates emissions to the characteristic times of distinct combustion subprocesses, with empirically determined model constants. In this paper, a new model is developed for lean premixed (LP) NO₂ emissions from a perforated plate flameholder combustor burning propane fuel. Several modifications to the diffusion flame CTM were required, including a new activation energy and a more complicated dependence on combustor pressure. Appropriate model constants were determined from the data, and the correlation results are reasonable. An attempt was made to validate the new model with LP NOₓ data for a different but geometrically similar flameholder operating at lower pressures. The predictions are good for the low equivalence ratio data. However, a systematic error in the reported equivalence ratios may be adversely affecting the predictions of the higher equivalence ratio data through the calculated adiabatic flame temperature.

NOMENCLATURE

CTM Characteristic Time Model
d_eff Effective diameter of a perforated plate flameholder based on area blockage
d_comb Combustor diameter at secondary penetration jet location
E Activation energy
l_no Characteristic NO quench length
l_probe Distance from flameholder trailing edge to gas sampling probe
l_sec Distance from fuel injector tip to centerline of secondary holes
LP Lean premixed
m_a Compressor airflow rate
m_pz Primary zone airflow rate
n Pressure exponent of lean premixed NO emissions
NOₓ Oxides of nitrogen, NO and NO₂
NOₓEI Oxides of nitrogen emissions index (g NOₓ as NO₂/kg fuel)
P Pressure
P₀ Reference pressure (1 atm)
r Correlation coefficient
R Universal gas constant
T Temperature

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INTRODUCTION

Lean premixed (LP) combustors offer reduced NOX emissions over conventional diffusion flame combustors because heterogeneous effects and stoichiometric contours are eliminated. Thus they operate at lower flame temperatures resulting in reduced thermal NOX produced via the Zeldovich mechanism (Zeldovich, 1946). However, other NOX pathways such as the prompt (Fenimore, 1971) and the nitrous oxide (Maitre and Pratt, 1974) mechanisms become increasingly important.

Several model types have been used to correlate or predict combustor emissions (Derr and Mellor, 1990). These range from purely empirical models obtained from multivariable regression analysis (that have no theoretical basis) to finite difference models which solve the conservation equations simultaneously at a grid of points throughout the combustor. However, purely empirical models are not valid for combustors with geometries and operating conditions other than those for which they were developed. Finite difference models do not give accurate results due to the lack of complete understanding of the processes involved (i.e. kinetics, turbulence, chemistry—turbulence interactions, etc.) (Mongia et al., 1986; Derr and Mellor, 1990).

Semi—empirical models fall between the two cases above. The algebraic equations used are based on consideration of combustion theory and combustor design practice, while their calibration constants are determined empirically by fitting measured data. Thus, to some extent such fitted equations are accurate for combustion systems other than those for which the calibration was accomplished since combustor, fuel type, geometry and operating conditions are taken into account. Semi—empirical models of this type have been used successfully to correlate and predict emissions from conventional diffusion flame combustors (Lefebvre, 1984; Derr and Mellor, 1990; Risk and Mongia, 1992a; Newbury and Mellor, 1994a,b), have led to a combustor design methodology (Mellor and Fritsky, 1990), and have been integrated into detailed computations for improved performance predictions (Risk and Mongia, 1989a, 1989b, 1992b). Similarly, having a phenomenological model able to predict the changes in emissions with the changes in geometry and operating conditions of LP combustors would prove beneficial to combustor designers.
DIFFUSION FLAME COMBUSTOR NO\textsubscript{x} MODEL

The semi-empirical characteristic time model (CTM) was first developed for laboratory flame-holders (Mellor, 1976; Tuttle et al., 1977) and then extended to conventional gas turbine combustors for emissions of nitric oxide, carbon monoxide, and unburned hydrocarbons (Mellor, 1977a, 1977b; Mellor and Washam, 1979). The thermal NO\textsubscript{x} model represents a single emissions correlation for 358 automotive, helicopter, industrial, and aircraft gas turbine data for four combustor geometries and various liquid fuels (Washam, 1979; Mellor and Washam, 1979):

\[
\text{NO}_x \text{EI}_{\phi=1} = 4.5 \left( \frac{r_{\text{ln}o}}{r_{no}} \right) \pm 3 \text{ (g/kg)}
\]  

(1)

where the emissions index, by convention expressed as g NO + NO\textsubscript{2} as NO\textsubscript{2} emitted per kg fuel burned, is used to eliminate dilution effects. The ± 3 g/kg in Eq. 1 above provides the estimated standard deviation of the prediction (Derr and Mellor, 1990), and the correlation coefficient is 0.97.

The characteristic kinetic time for NO formation, \(r_{no}\), is given by:

\[
r_{no} = Z \exp\left(\frac{E_{no}}{RT} \right)_{\phi=1}
\]

(2)

where \(E_{no}\) is an empirical activation energy (135 kcal/gmol) for thermal NO formation close to that for the Zeldovich mechanism assuming N is in steady state and O and O\textsubscript{2} are in equilibrium (135,500 cal/gmol; Washam, 1979). The pre-exponential factor, Z, is chosen to be 10\textsuperscript{12}, so that \(r_{no}\) is on the order of milliseconds (Tuttle et al., 1977).

The shear layer quenching time for thermal NO\textsubscript{x} formation, \(T_{\text{almo}}\), is thought proportional to the stoichiometric (i.e., NO-forming) eddy lifetime in the trailing edge of the shear layer surrounding the flameholding recirculation zone, where the majority of thermal NO\textsubscript{x} formation occurs (Tuttle et al., 1977):

\[
T_{\text{almo}} = \frac{\text{ln}o}{V_{\phi=1}}
\]

(3)

For combustors, \(l_{no}\), the characteristic NO quench length, takes the form (Mellor, 1977a):

\[
l_{no} = \left( \frac{\text{sec}}{\text{comb}} \right)^{-1} + (d_{\text{comb}})^{-1}
\]

(4)

that is similar to the integral length scale for a right circular cylinder of diameter \(d_{\text{comb}}\) truncated at length \(l_{\text{sec}}\) (Ferguson, 1986). The angle of the blades in any dome swirler is denoted \(\theta\). The stoichiometric flame zone velocity (\(V_{\phi=1}\)) is expressed as a fraction of the reference velocity (Washam, 1979; Mellor and Washam, 1979):

\[
V_{\phi=1} = \left( \frac{m_{apz}}{m_a} \right) \left( \frac{T_{\phi=1}}{T_{in}} \right) V_{\text{ref}}
\]

(5)

where \(m_{apz}\) is the air flow rate through the primary zone (Washam, 1979; Mellor and Washam, 1979).

The ratio \(r_{almo}/r_{no}\) represents a Damköhler number (i.e., a fluid time divided by a kinetic time) for NO formation and is termed the characteristic time ratio. Thus, the CTM is a semi-empirical scaling procedure where the emissions index of nitrogen oxides has been found to scale linearly with this Damköhler number for diffusion flame combustors (Mellor and Ferguson, 1980). However, for LP combustion both the fluid time and the kinetic time may be different, so the appropriate Damköhler number is sought.

LEAN PREMIXED NO\textsubscript{x} CHARACTERISTIC TIME MODEL DEVELOPMENT

Experimental Data

Tacina (1990) gives a summary of the available LP NO\textsubscript{x} data, from which those of Roffe and Venkataramani (1978) utilizing propane vapor/air mixtures burning on a perforated plate flameholder were chosen for analysis since pressures as high as 30 atm were investigated. Adiabatic flame temperatures listed by Roffe and Venkataramani (1978) were estimated from charts (Venkataramani, 1994), so for the following analysis, flame temperatures were calculated with the thermochemical code STANJAN (Reynolds, 1987), based on the fuel composition and the fuel/air equivalence ratios reported by Roffe and Venkataramani (1978). Table 1 lists the present (STANJAN) adiabatic flame temperatures at equilibrium (TΦ) along with those reported by Roffe and Venkataramani (1978) (termed GASL), as well as the operating conditions and the NO\textsubscript{x} emissions data. The STANJAN temperatures are around 20 to 50 K lower than the GASL temperatures for all of the cases. Venkataramani (1994) using Gordon and McBride (1971) was able to reproduce the STANJAN temperatures. Data at air inlet temperature of 727 K are not used because a malfunction in the test rig temperature controller occurred (Roffe and Venkataramani, 1978).

Kinetic Time

The pressure dependence of lean premixed NO\textsubscript{x}
emissions, a major controversy (see for example Aigner et al. (1990)), is based on the kinetic mechanism of Drake and Blint (1991) used in the CH₄/air computations of Nicol et al. (1992), who modeled the effects of inlet pressure, Pᵢn, on measured total lean NOₓ emissions as

$$NOₓ (\text{ppmv} \times 15\% \text{O}_2) \propto Pᵢn^n$$

where the value of n varies depending on inlet conditions and equivalence ratio. At a given equivalence ratio

$$NOₓEI \propto NOₓ (\text{ppmv} \times 15\% \text{O}_2)$$

Thus, the pressure dependence will be modeled here as

$$NOₓEI \propto Pᵢn^n$$

Since $\tau_{sl,tno}$ is inherently proportional to $Pᵢn$, a new kinetic time for NO formation will be defined:

$$\tau_{tno} = 2(Pᵢn/P₀)^{1-n} \times \exp(E_{tno}/RTₚ)$$

where $P₀$ is a reference pressure used to non-dimensionalize the pressure term. The pre-exponential factor, Z, and the activation energy, $E_{tno}$, are determined empirically, and the values of n are estimated based on the computations of Nicol et al. (1993). The subscript "tno" indicates the total NO formation mechanism (i.e., a combination of the Zeldovich, prompt, and nitrous oxide mechanisms).

**Mixing Time**

The expression for $\tau_{sl,tno}$ (Eq. 3) will also change since $Tϕ=1$ in Eq. 5 is replaced by $Tϕ$. Therefore,

$$\tau_{sl,tno} = l_{tno}/Vϕ$$

where

$$Vϕ = (m_{air}/mA)(Tϕ/T₁n)V_{ref}$$

Since Roffe and Venkataramani (1978) used a perforated plate flameholder, all of the air passed through the primary zone. Thus, Eq. 11 reduces to:

$$Vϕ = (Tϕ/T₁n)V_{ref}$$

Roffe and Venkataramani (1978) positioned their gas sampling probe at a residence time of 2 ms downstream of their perforated plate flameholder, where the axial location of the probe ($l_{probe}$) was adjusted for each run according to the velocity at the temperature of the burned gas at the overall equivalence ratio ($Vϕ$). We have thus defined their residence time as

$$\tau_{res} = l_{probe}/Vϕ = l_{probe}/(TϕGASL/T₁n)V_{ref}$$

where $TϕGASL$ is the appropriate test temperature reported in Roffe and Venkataramani (1978) and listed in Table 1. Also, they used a constant reference velocity ($V_{ref}$) of 25 m/s for all runs. Therefore,

$$l_{probe} = 2 \times 10^{-3} \text{ s} \times 25 \text{ (m/s)}(TϕGASL/T₁n) \text{ (m)}$$

Venkataramani (1994) concurred that this was the appropriate definition.

The length scale, $l_{no}$, is evaluated by Eq. 4 in terms of the NO quench location. Setting $l_{sec}$ equal to $l_{probe}$ as computed above for the experiments of Roffe and Venkataramani (1978) implies that quenching of NO formation occurs at the leading edge of their gas sampling probe. This is believed to be true since three probe designs were tested, and they all gave similar NOₓ results (Roffe and Venkataramani, 1978).

There are two ways to evaluate $d_{comb}$ for these tests. The first is to use 0.079 m, the inner diameter of the combustor. However, this practice would predict no effect of changing the perforated plate blockage on NOₓEI, an unlikely result in view of the findings of Tuttle et al. (1977). Therefore, the second approach, used here, is to define an effective diameter, $d_{eff}$, of a circular (disc) flameholder which has the same blockage (78% by area) as the perforated plate actually utilized in the tests. Thus, Eq. 4 reduces to

$$l_{no}^{-1} = (l_{probe})^{-1} + (d_{eff})^{-1}$$

where $d_{eff} = 0.07$ m.

**LP MODEL VALIDATION**

The data of Table 1 are presented graphically in Arrhenius form in Fig. 1 as $\ln[NOₓEI/τ_{sl,tno}]$ versus inverse adiabatic flame temperature computed for the listed overall equivalence ratio via STANJAN, as discussed previously. After dividing NOₓEI by $τ_{sl,tno}$, the differing magnitudes and slopes are due to the variation of the pressure exponent with $T₁n$, $Pᵢn$ and $ϕ$ which has not been taken into account. The solid lines in Fig. 1 are least square fits of the datum groups and yield the activation energies for total NOₓEI formation given in the figure. Weighting those values according to the number of
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<th>$T_{in,a}$, K</th>
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**Note:**

aGASL experiments modeled as $0.9\text{C}_3\text{H}_8 + 0.1\text{C}_3\text{H}_6 + (4.95/\phi)(\text{O}_2 + 3.76\text{N}_2) \rightarrow \text{Equilibrium Products at Constant Pressure and Enthalpy.} \quad \Box$
points in each datum set gives an overall $E_{\text{t}_{\text{no}}}$ equal to 39.7 kcal/gmol, substantially different from that associated with the modified Zeldovich mechanism because it reflects contributions from thermal, prompt, and nitrous oxide NO. The latter two become a more significant fraction of the total as the equivalence ratio becomes leaner.

The justification for assigning a single global activation energy to the three mechanisms lies in the fact that there is little change in the slopes of Fig. 1. In addition, detailed chemical reactor modeling including all three mechanisms for NO formation in propane combustion at the Roffe and Venkataramani (1978) conditions of fuel–air equivalence ratios from 0.4 to 0.6 produces an overall activation energy of 42.5 kcal/gmol (Malte, 1994). In Eq. (9), the pre–exponential factor, $Z$, is chosen to be $10^{11}$ ms to give the values of $\tau_{\text{t}_{\text{no}}}$ the same order as the values of $\tau_{\text{s}_{\text{I}}, \text{t}_{\text{no}}}$. This yields the expression:

$$\tau_{\text{t}_{\text{no}}} = 10^{-5} (P_{\text{in}}/P_{0})^{1-n} \times \exp \left[\frac{39700}{RT_{\phi}}\right] (\text{ms})$$

(16)

For each of the four datum sets (defined by differences in inlet pressure and/or temperature) linear regressions of NO$_{x}$EI versus $\tau_{\text{s}_{\text{I}}, \text{t}_{\text{no}}} / \tau_{\text{t}_{\text{no}}}$ were performed for values of $n$ varying from 0 to 0.6 based on Nicol et al. (1992). It was observed that the correlation coefficients of the fits for the individual datum sets remained constant and the y–intercept varied from zero to only a small degree. It was therefore assumed that the y–intercepts were negligible and that to obtain the best correlation one need only make the slopes of the best fit lines for each datum set equal.

Using this assumption, values of $n$ were determined for each set. The resulting CTM correlation, along with the values of $n$ used are shown in Fig. 2. Linear regression of the data in Fig. 2 yields the LP CTM predicting equation:

$$\text{NO}_x\text{EI}|_{\phi<1} = 4.21 \tau_{\text{s}_{\text{I}}, \text{t}_{\text{no}}} / \tau_{\text{t}_{\text{no}}} + 0.15 \pm 0.67 \text{ (g/kg)}$$

(17)

where the correlation coefficient equals 0.987, and $\pm 0.67$ (g/kg) is the standard deviation of the 40 data. Some uncertainty in Fig. 2 is due to assuming $n$ is constant for each data set, which does not account for the variation of $n$ with equivalence ratio (Nicol et al., 1992). Also, new pressure exponents are reported in Nicol et al. (1993) for three CH$_4$/air kinetic mechanisms (Miller and Bowman, 1989; Drake and Blint, 1991; Michaud et al., 1992). Table 2 lists the values of $n$ reported in Nicol et al. (1993) along with those from the present analysis for the Roffe and Venkataramani (1978) inlet temperatures and pressures. Although the reported (Nicol et al., 1993) pressure exponents vary with both the equivalence ratio and kinetic mechanism at each operating condition, the pressure exponents from the present study are within the computed range for each case. Thus, since no definite pattern as to how $n$ varies with mechanism or equivalence ratio is apparent in Table 2, $n$ was not changed for each equivalence ratio used in the experiments.

**LP MODEL APPLICATION**

Other measurements on NO$_x$ emissions from lean premixed combustion (Tacina, 1990) also with C$_3$H$_8$ fuel and a perforated plate flameholder are limited to the data obtained by Anderson (1975), who varied combustor residence time and used lower combustor pressure than Roffe and Venkataramani (1978). The data from Anderson (1975) exhibit two major problems; however: first, the NO$_x$ does not peak at an equivalence ratio near one; and second, the equivalence ratio based on the measured carbon balance is only around nine–tenths that of the equivalence ratio from the inlet flow rate measurements. Anderson (1975) believed that the second difficulty was caused by errors in the inlet flow measurement equipment. Therefore, he reported all of the data based on the carbon balance equivalence ratios.

The NO$_x$ data from Anderson (1975) provide a test for the LP NO$_x$ CTM with a different but geometrically similar combustor, different inlet conditions, and varying residence times. The approach taken is to use the correlation of Roffe and Venkataramani's (1978) data (Eq. 17) with pressure dependencies estimated from Nicol et al. (1993) to predict the lean NO$_x$ emissions measured by Anderson (1975). The method of data reduction and analysis is identical to that employed for the data of Roffe and Venkataramani (1978).

Figure 3 shows the results for both Anderson's 600 K and 800 K lean data up to NO$_x$EI$_{\text{max}}$. The CTM predicted line is given by Eq. 17, only drawn to $\tau_{\text{s}_{\text{I}}, \text{t}_{\text{no}}} / \tau_{\text{t}_{\text{no}}} = 2.8$ since the Roffe and Venkataramani (1978) data only extend to that point. This is shown in Fig. 4, which expands the lower left of Fig. 3 with the data of Roffe and Venkataramani included. In Figs. 3 and 4, the 10 cm probe position data agree most closely with the

<table>
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<th>P_in (atm)</th>
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<th>n for φ=0.6 from Nicol et al. (1993)</th>
<th>n for φ=0.7 from Nicol et al. (1993)</th>
<th>Mechanism used in Nicol et al. (1993)</th>
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<td>0.44</td>
<td>0.44</td>
<td>MWF</td>
</tr>
</tbody>
</table>

CTM prediction for both the 600 K and 800 K cases. Also, at small values of $\tau_{sl}/\tau_{no}$, the 20 and 30 cm data generally agree with the prediction as well, but the discrepancy increases nonlinearly with increasing characteristic time ratio to unacceptable values for φ ≥ 0.7 or larger.

An analysis has been performed to determine what may have caused the differences between the prediction and the results at 20 and 30 cm for larger characteristic time ratios. Since there are two variables in Eq. 17, $\tau_{sl}$ and $\tau_{no}$, both of these were examined separately.

The characteristic mixing time is given by Eq. 10

where $l_{no}$ is the characteristic length for NOX formation (Eq. 15), and V $\phi$ is the combustor flow velocity (Eq. 12). Since the only independent variable in V $\phi$ is T $\phi$, which will be discussed later because it also occurs in the equation for $\tau_{no}$, first $l_{no}$ was examined. However, to collapse the high equivalence ratio (high NOX EI) data in Fig. 3 to the extrapolated position of the predicted line, unreasonable values for d_eff greater than d_comb or negative values for l_probe are required.

The characteristic kinetic time for lean premixed NOX formation is given by Eq. 16 in which the only independent variables are n and T $\phi$. Average values of the pressure exponents reported in Nicol et al. (1993) for the three different NOX formation mechanisms at a constant residence time of 5 ms at 1 and 10 atm were used in Figs. 3 and 4 for each inlet temperature (the residence times of Anderson (1975) range from 0.97 to 5.35 ms). Values of n greater than 0.8 were needed for agreement of high equivalence ratio data and predictions and seem unreasonable because the highest n given in Nicol et al. (1993) for either the 600 K or 800 K inlet temperatures at inlet pressures of 10 atm or less was 0.67, and for 800 K at any pressure the highest n was 0.62. Also, using values of n greater than 0.8 worsened the low equivalence ratio NOX EI data comparison with the predictions. Therefore, it is believed that the values of n used to develop Fig. 3 and 4 are adequate.

The T $\phi$ term is present in both the equations for $\tau_{sl}/\tau_{no}$ (Eq. 10) and $\tau_{no}$ (Eq. 16). However, T $\phi$ is in the exponential in Eq. 16, so it has a much greater
effect there. One uncertainty in Anderson's data discussed above concerns the equivalence ratio. The effect of raising the equivalence ratio by 10% is to increase \( T_{\phi} \) by over 100 K in the near stoichiometric cases, which brings the high NO\(_x\) EI data into agreement with the extrapolated prediction without using pressure exponents greater than 0.62. The lower equivalence ratio points are not affected as significantly. Therefore, the errors in the equivalence ratios can account for the discrepancies in Fig. 3. Also, Anderson reported the highest NO\(_x\) values of any of the experiments listed in Tacina (1990). This may be due to a lack of proper quenching in Anderson's (1975) probe. Unlike Roffe and Venkataramani (1978), Anderson (1975) did not use more than one probe design to verify its quenching ability.

CONCLUSIONS

The characteristic time model, previously applied to conventional diffusion flame combustors, was extended to NO\(_x\) emissions data for C\(_3\)H\(_8\)/air flames at high pressures stabilised on a perforated plate to develop a new lean premixed correlation. This correlation was then used to predict similar data from another laboratory obtained at lower pressures. The predictions were reasonable at low equivalence ratios. However, at high equivalence ratios, the data are largely underpredicted. There is enough uncertainty in the second set of data to account for this, but several other possible causes for this discrepancy should be investigated experimentally.

First, the effect of residence times on the pressure exponents has not been taken into account. Second, the dependence of the pressure exponents on the fuel type is unknown. The available calculations are based on methane/air kinetic mechanisms, while both experiments considered here used propane. Third, the mixing time expression was developed for diffusion flame combustion where the majority of the NO is Zeldovich and forms in downstream regions of the stoichiometric shear layer. Applying this expression to lean premixed systems does not account for the expected upstream locations of prompt and nitrous oxide NO formation. Without perforated plate flameholder geometry variations in either set of experiments, the proper length scale for LP NO\(_x\) emissions cannot be ascertained. Fourth, fuel/air unmixedness (both spatial and temporal) was not characterized in either experiment, and Fric (1993) has demonstrated experimentally that both can contribute significantly to higher NO\(_x\) emissions.

Although these uncertainties do exist, the data from the first laboratory were correlated with a standard deviation of 0.67 g/kg, and the leanest results in the second study, at equivalence ratios of most practical significance from the NO\(_x\) control viewpoint, were predicted. With experiments designed to clarify the uncertainties discussed above, the model validation can be pursued.

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**FIGURE 1.** ARRHENIUS PLOT OF THE NO\textsubscript{x} DATA OF ROFFE AND VENKATARAMANI (1978) LISTED IN TABLE 1. NO\textsubscript{x}EI IS EXPRESSED IN g/kg AND τ\textsubscript{sl}τ\textsubscript{ino} IN MILLISECONDS.

**FIGURE 2.** OVERALL CORRELATION OF THE TOTAL NITRIC OXIDE EMISSIONS DATA OF ROFFE AND VENKATARAMANI (1978) USING PRESSURE DEPENDENCE VALUES OF (1) n = 0.054 FOR 10 atm, 600 K; (2) n = 0.520 FOR 30 atm, 600 K; (3) n = 0.365 FOR 10 atm, 800 K; AND (4) n = 0.545 FOR 30 atm, 800 K; V\textsubscript{ref} = 25 m/s; τ\textsubscript{res} = 2 ms; r = 0.987; σ\textsubscript{y} = 0.670.
FIGURE 3. NO\textsubscript{x}EI VERSUS $\tau_{\text{sl,tno}}/\tau_{\text{tno}}$ FOR THE DATA OF ANDERSON (1975); $P_{\text{in}} = 5.5$ atm; $V_{\text{ref}} = 25$ m/s; LP CTM PREDICTION LINE GIVEN BY EQ. (17).

FIGURE 4. NO\textsubscript{x}EI VERSUS $\tau_{\text{sl,tno}}/\tau_{\text{tno}}$ FOR BOTH ANDERSON'S (1975) AND ROFFE AND VENKATARAMANIS (1978) DATA FOR $\tau_{\text{sl,tno}}/\tau_{\text{tno}} < 3$. 