NASA Forum Presentation

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Emissions Measurements for a Lean Premixed Propane/Air System at Pressures Up to 30 Atmospheres

A series of experiments was conducted in which the emissions of a lean premixed system of propane and air were measured at pressures of 5, 10, 20 and 30 atm in a flametube apparatus. Measurements were made for inlet temperatures between 600K and 1000K and combustor residence times from 1.0 to 3.0 msec.

Figure 1 is a schematic of the test rig. Propane, heated to a temperature of 380K, was injected as a gas through a 52 point matrix into a dry heated stream of air. The mixture was ignited downstream of a water-cooled perforated plate flameholder and emissions measured at downstream locations by a water-cooled sampling probe. Residence time was calculated from probe position assuming an instantaneous temperature rise to the adiabatic flame temperature.

Figures 2, 3 and 4 present emissions measurements for NO_x, CO and UHC as functions of combustor residence time for various equivalence ratios, entrance temperatures and pressures. NO_x emission index appears to vary directly with residence time. Hydrocarbon species disappear within the first two milliseconds. CO levels peak around one millisecond and then fall rapidly until equilibrium is reached sometime between 2.0 and 2.5 milliseconds residence time.

Figure 5 illustrates typical behavior of emissions as a function of equivalence ratio for a fixed residence time. NO_x levels rise exponentially from the lean stability limit but tend to flatten out at high equivalence ratio. CO drops rapidly as equivalence ratio increases from the lean stability limit eventually reaching chemical equilibrium within the fixed combustor residence time and follows the equilibrium curve from that point on. Unburned hydrocarbon levels decrease with increasing equivalence ratio.

Figures 6 through 10 present correlations of NO_x emission index with adiabatic flame temperature for a fixed residence time of 2 msec and pressures from 5 to 30 atm. Adiabatic flame temperature is seen to be an excellent correlating parameter, combining the individual effects of entrance temperature and equivalence ratio. Furthermore, there appears to be a universal curve which fits

all NO_x emission data, independent of pressure. At operating conditions combining low inlet temperature and low pressure, some NO_x data falls below this universal curve. It is likely that this is simply a reflection of the inadequacy of the assumption of instantaneous temperature rise in the residence time calculation at these conditions.

Figure 11 illustrates the pressure reduction sampling probe used to obtain the preceding data. The high pressure gas sample was first expanded into a low pressure (2 atm) dump tube to slow reactions. A small portion of this low pressure sample was then withdrawn through a water-cooled tube and analyzed for emissions.

Figure 12 illustrates a rapid thermal quench sampling probe which maintains a constant pressure in the sampling tube.

Figure 13 illustrates a sampling probe which combines the pressure reduction and rapid thermal quench techniques in a single design.

Figure 14 illustrates how sampling probe design affects emission measurements. NO_x and UHC measurements are virtually identical using thermal, pressure and pressure/thermal quenching techniques. CO levels are quite sensitive to quench technique and can drop substantially in the sampling probe if reaction rates are not adequately retarded. Since a straight pressure reduction sampling probe was used to obtain the emissions data presented in Figures (1) through (4), CO levels reported there are probably lower than actual. The breakpoint, or point at which measured CO levels cross the equilibrium curve and reverse their slope, is not affected by this phenomenon.

Figure 15 presents the adiabatic flame temperature corresponding to CO breakpoint conditions for 2 msec residence time as a function of inlet temperature and pressure. An adiabatic flame temperature of 2050K is seen to be a good correlation of the breakpoint phenomenon.

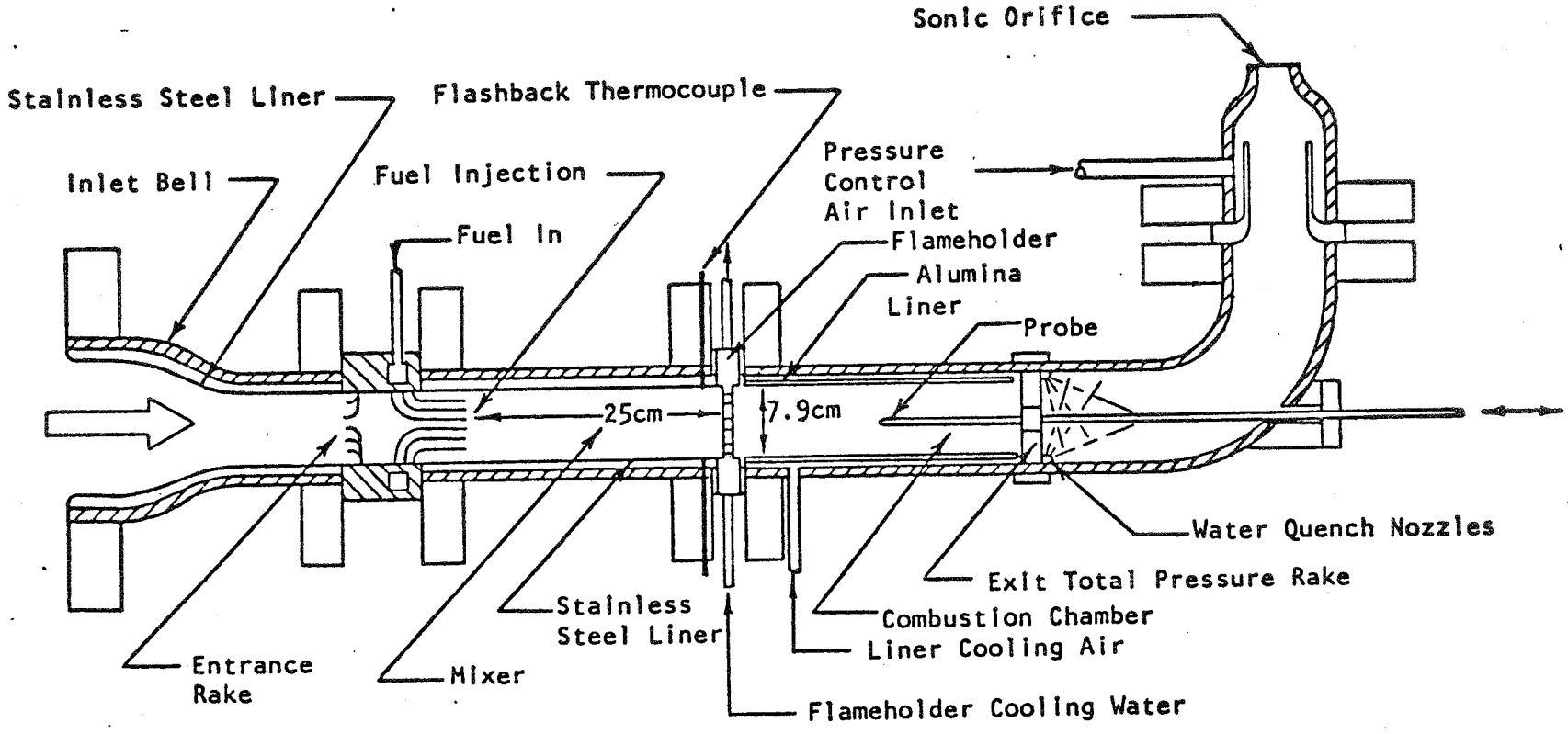


FIGURE 1. COMBUSTION TEST RIG

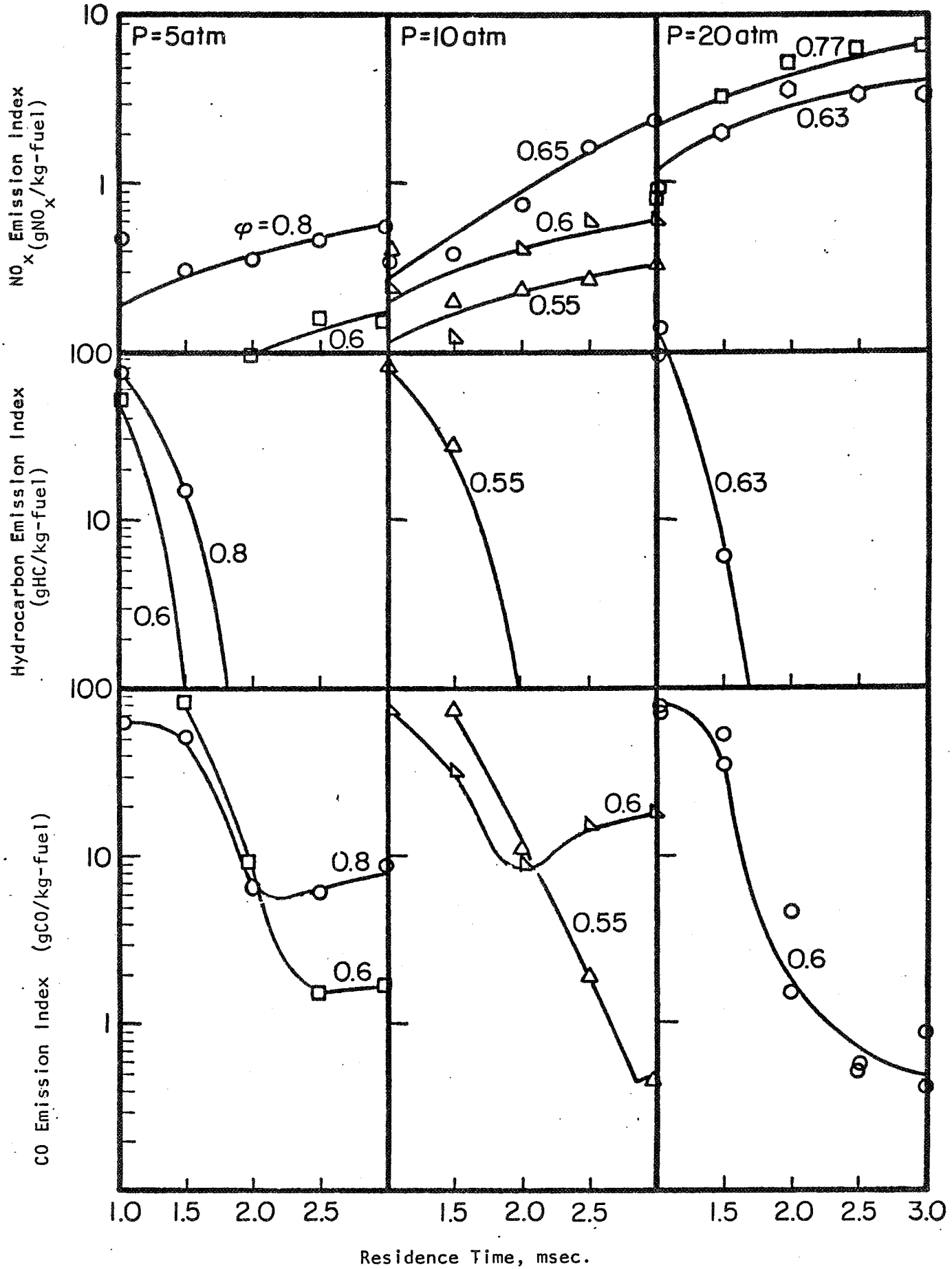


FIGURE 2. EMISSION INDICES AS A FUNCTION OF COMBUSTOR RESIDENCE TIME (T_3=600K)

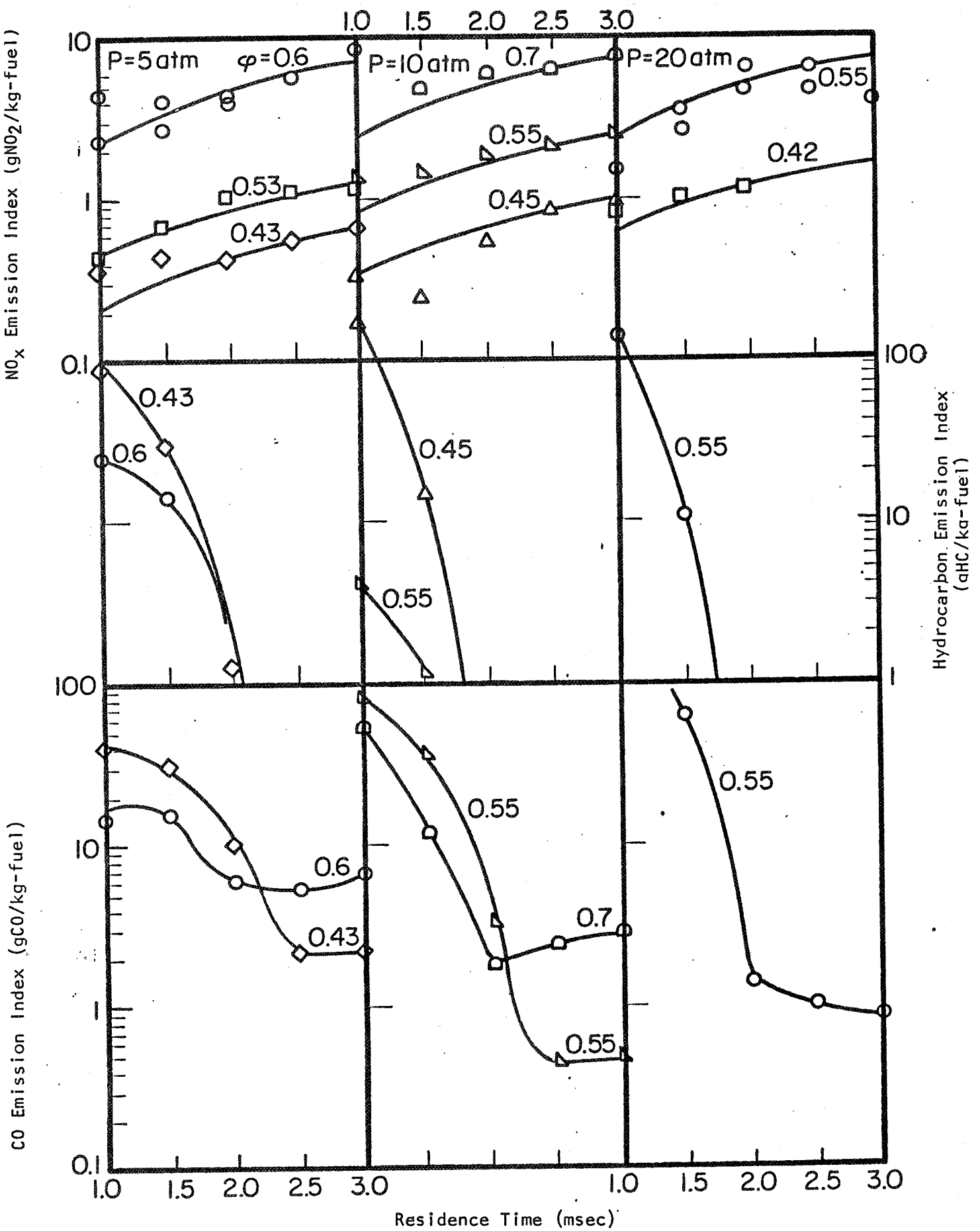


FIGURE 3. EMISSION INDICES AS A FUNCTION OF COMBUSTOR RESIDENCE TIME (T_3=800K)

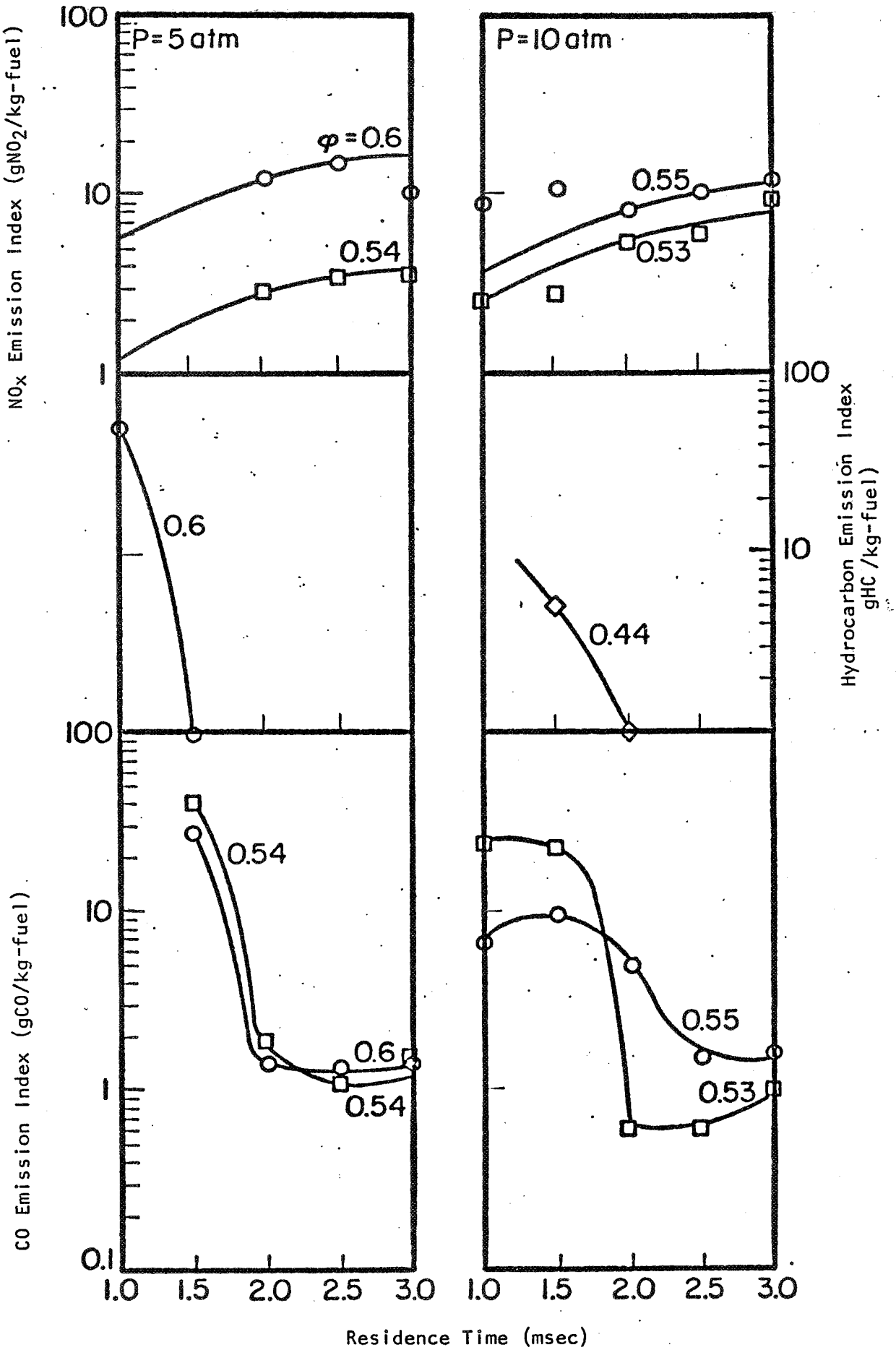
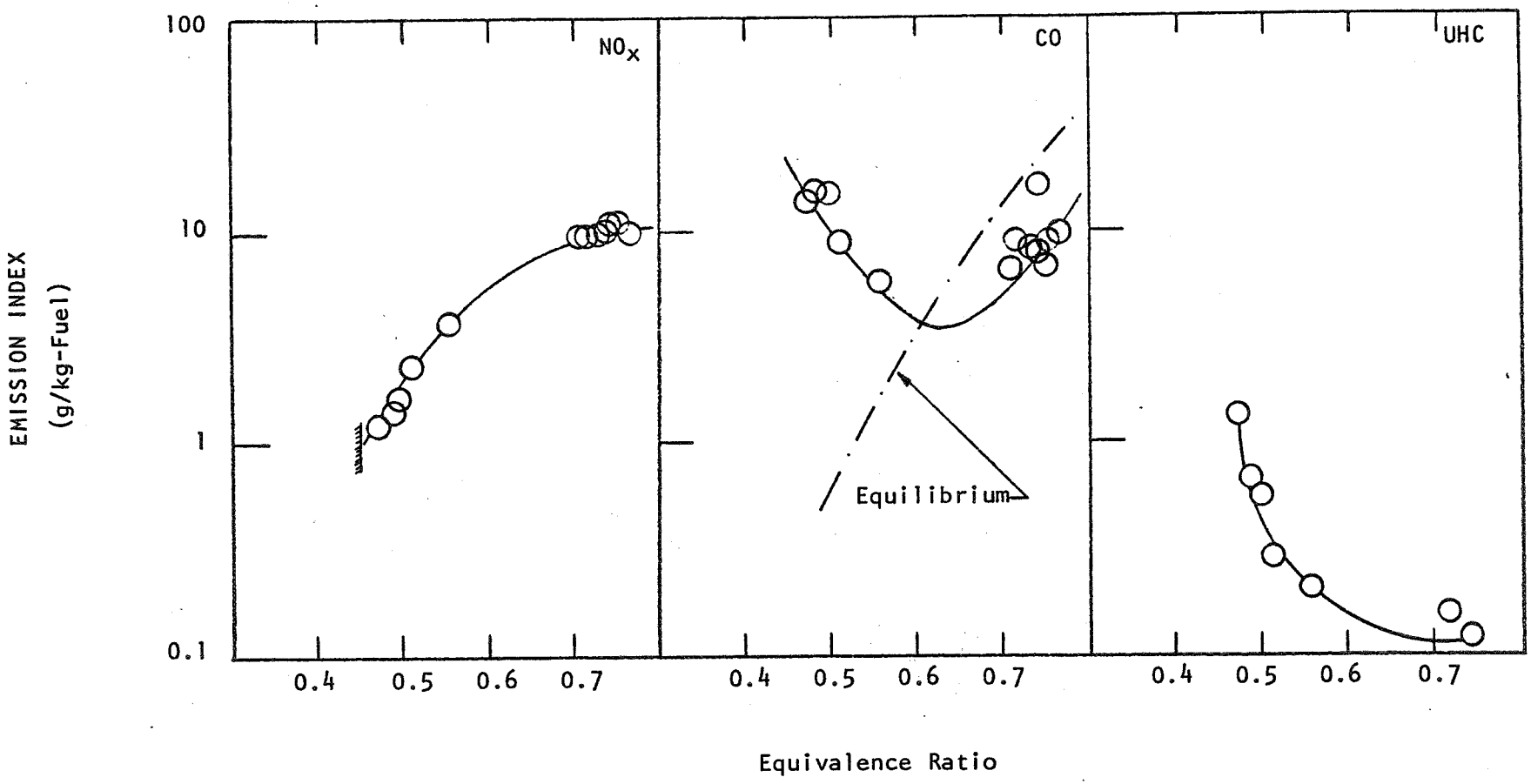


FIGURE 4. EMISSION INDICES AS A FUNCTION OF COMBUSTOR RESIDENCE TIME (T_3=1000K)



Inlet Temperature = 800K

Inlet Pressure = 30 atm

Residence Time = 2 msec

FIGURE 5. EMISSION MEASUREMENTS

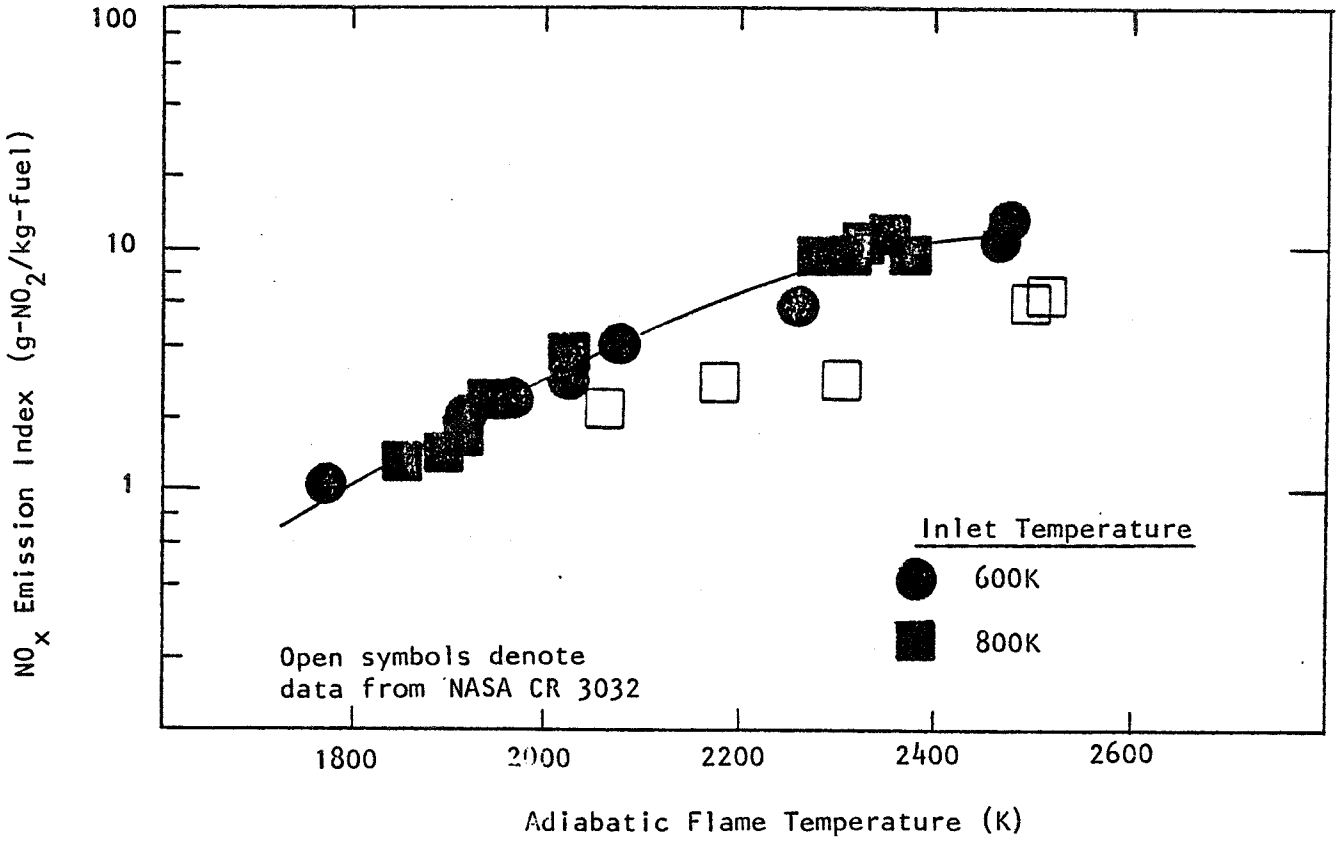


FIGURE 6. CORRELATION OF NO_x EMISSION INDEX FOR 2 MSEC RESIDENCE TIME WITH ADIABATIC FLAME TEMPERATURE (P=30 atm)

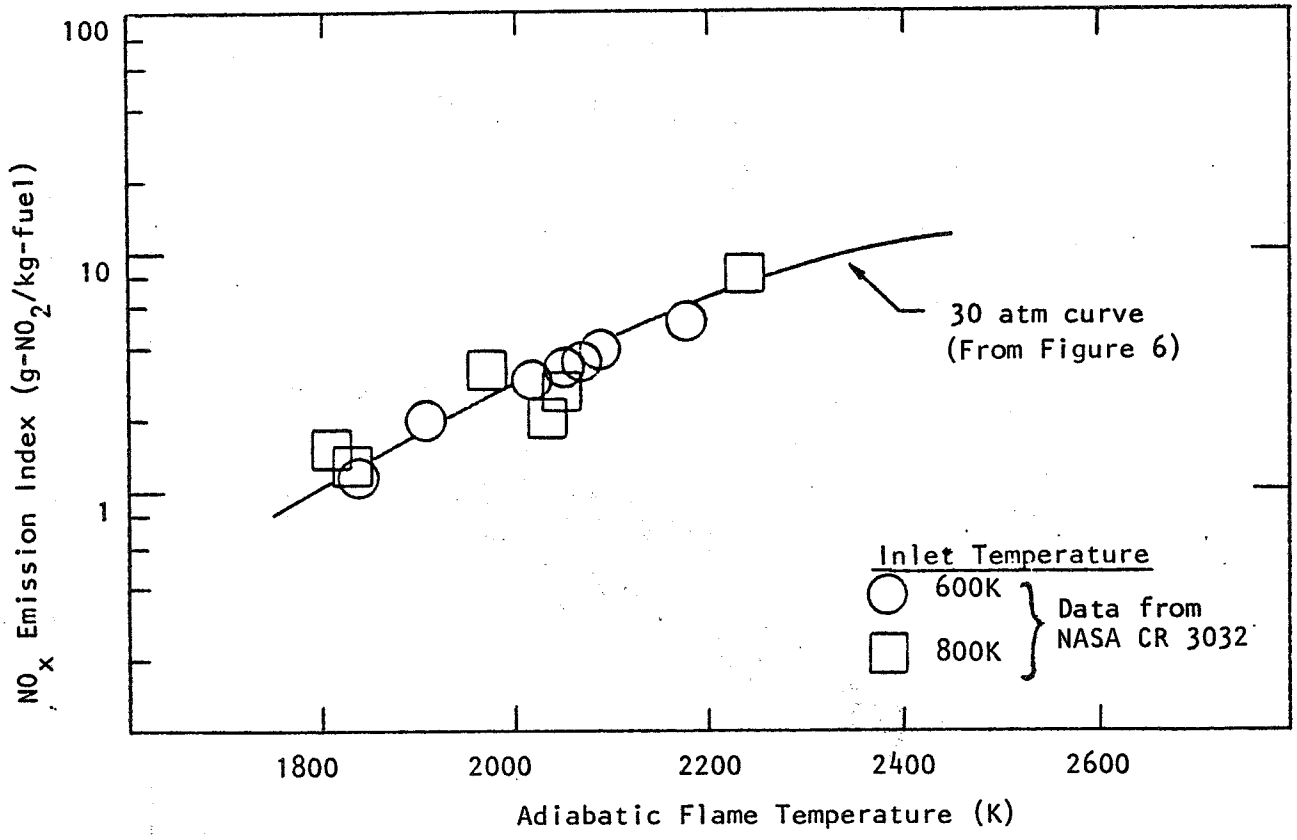


FIGURE 7. CORRELATION OF NO_X EMISSION INDEX FOR 2 MSEC RESIDENCE TIME WITH ADIABATIC FLAME TEMPERATURE (p=20 atm)

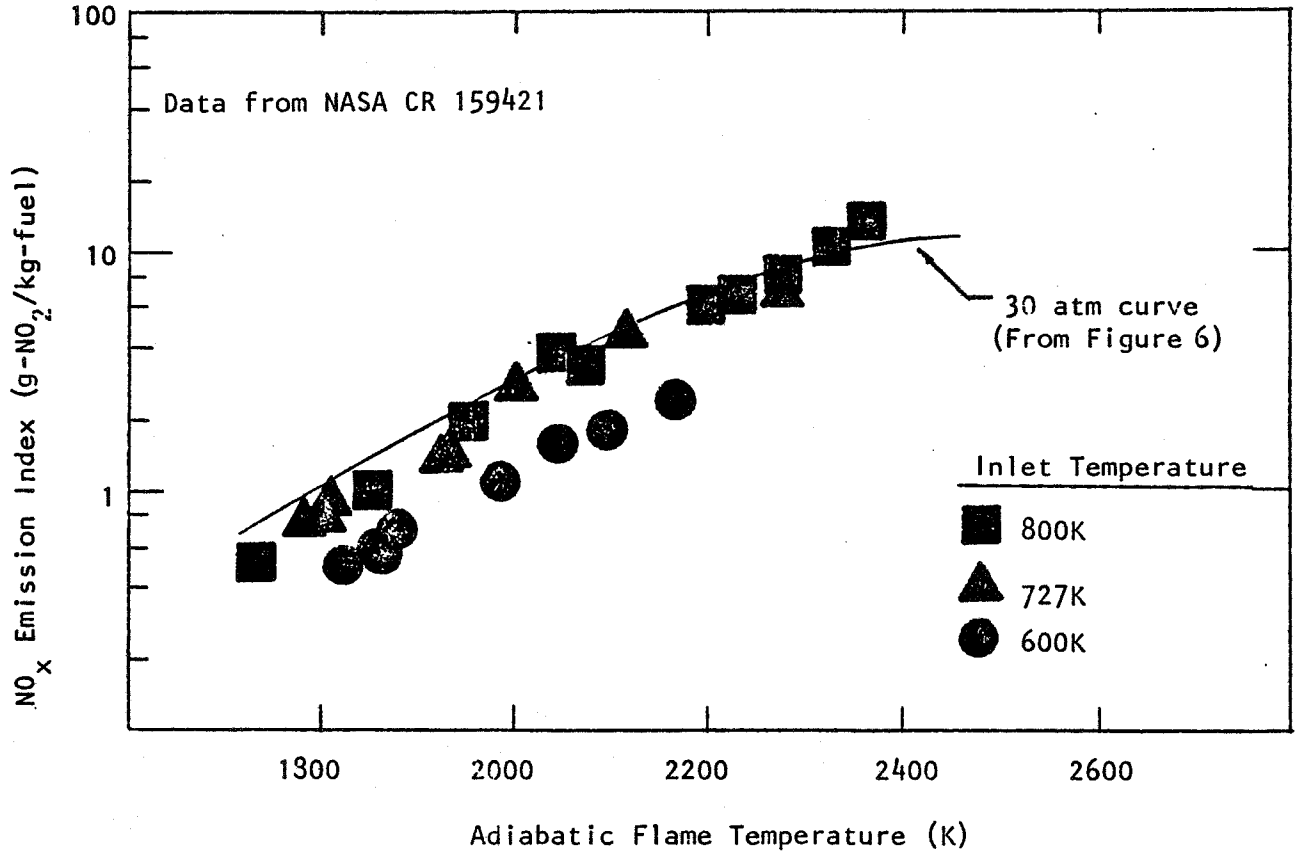


FIGURE 8. CORRELATION OF NO_X EMISSION INDEX FOR 2MSEC RESIDENCE TIME WITH ADIABATIC FLAME TEMPERATURE. (P=10 atm)

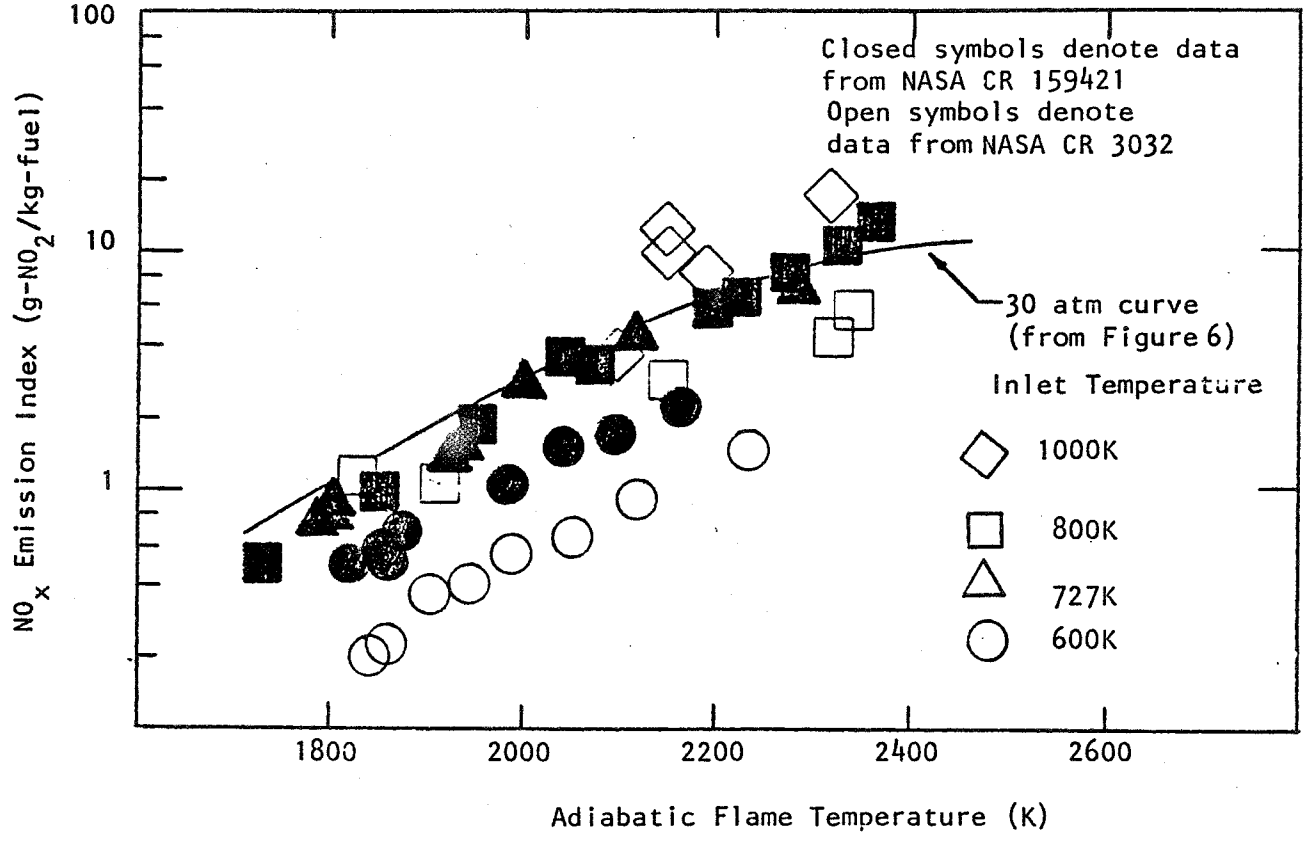


FIGURE 9. CORRELATION OF NO_x EMISSION INDEX FOR 2MSEC RESIDENCE TIME WITH ADIABATIC FLAME TEMPERATURE (P=10 atm)

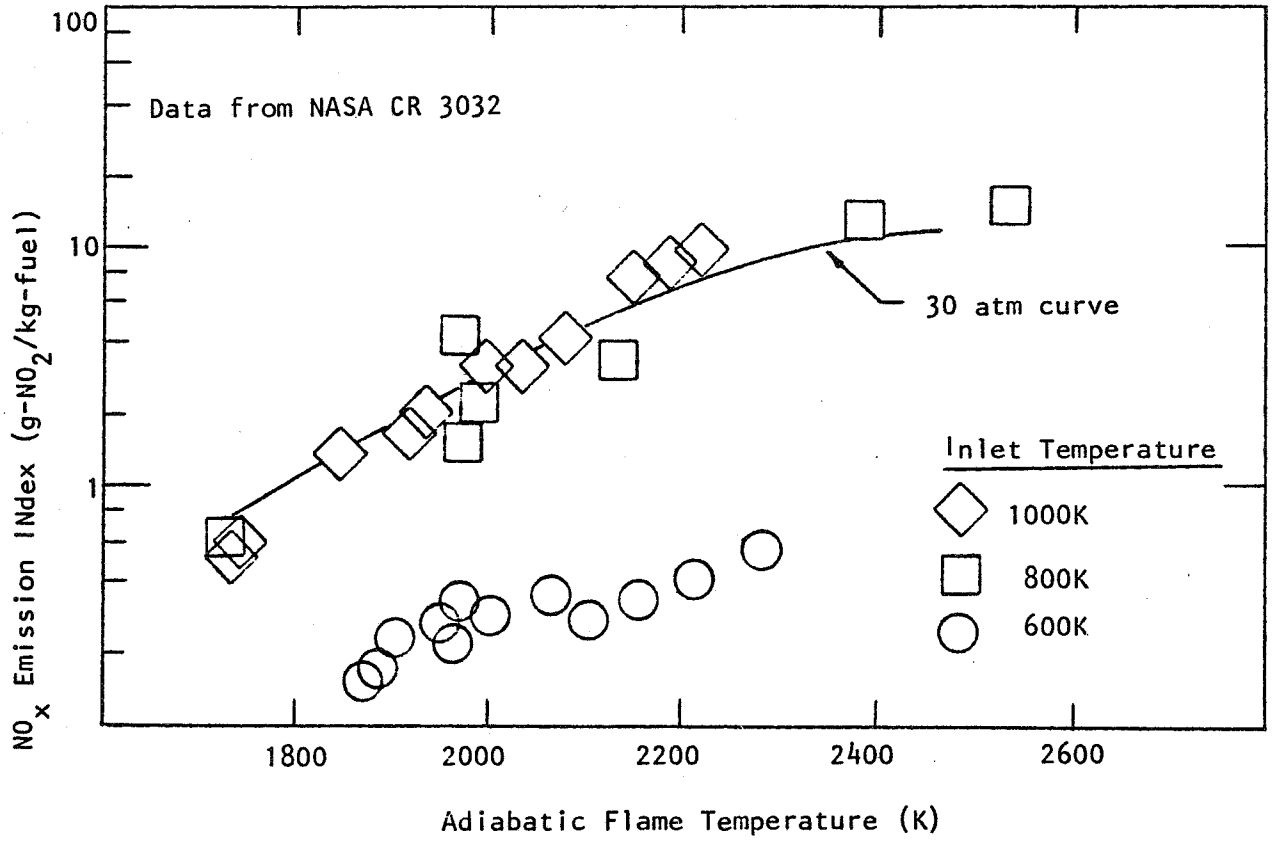


FIGURE 10. CORRELATION OF NO_x EMISSION INDEX FOR 2 MSEC RESIDENCE TIME WITH ADIABATIC FLAME TEMPERATURE (p=5 atm)

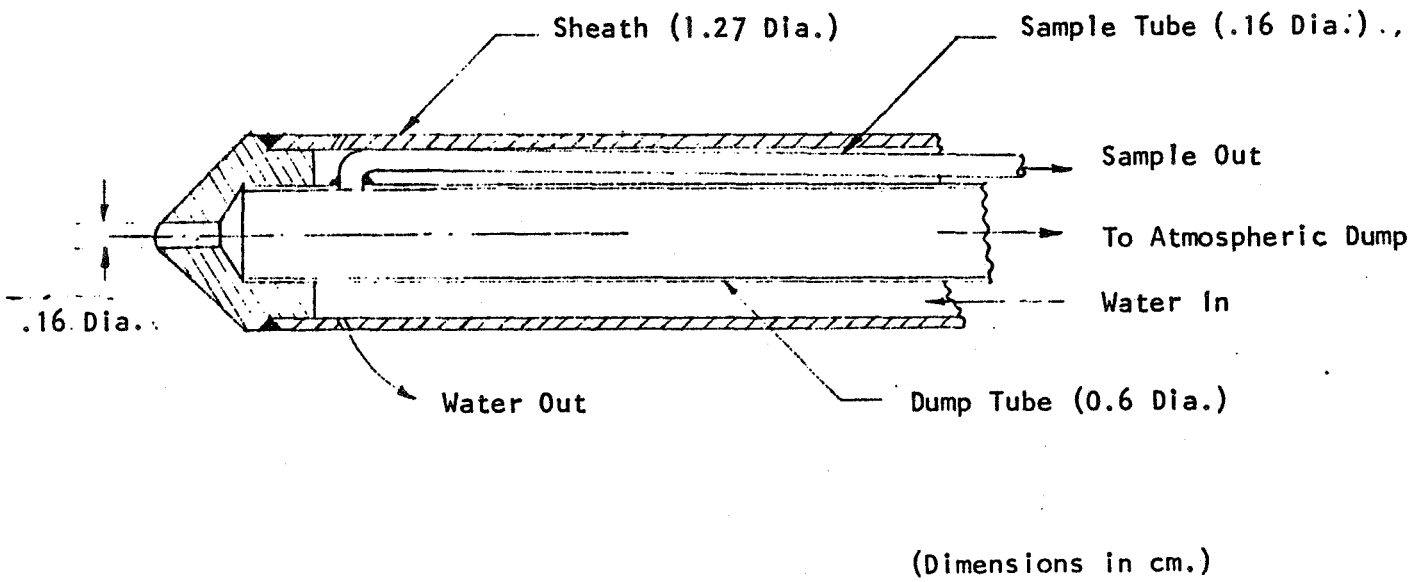
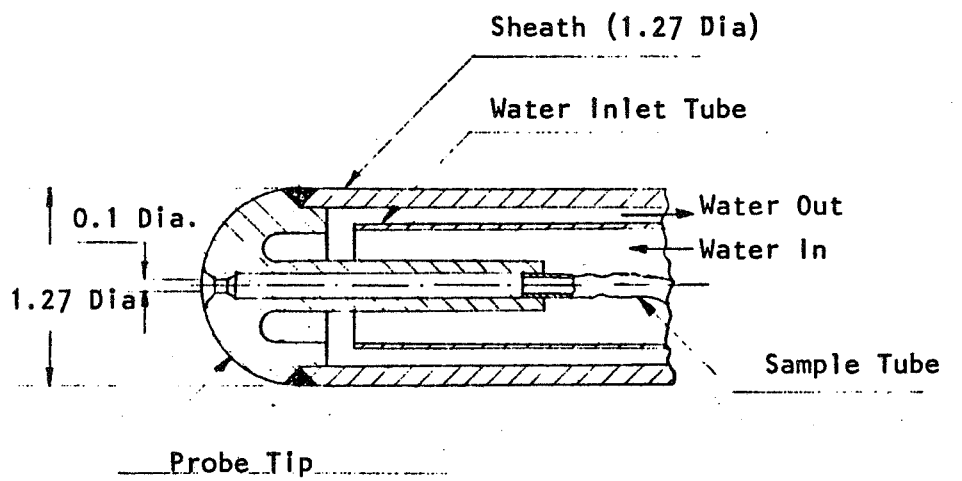


FIGURE 11. PRESSURE REDUCTION SAMPLING PROBE WITH MODERATE THERMAL QUENCH



(Dimensions in cm.)

FIGURE 12. THERMAL QUENCH PROBE

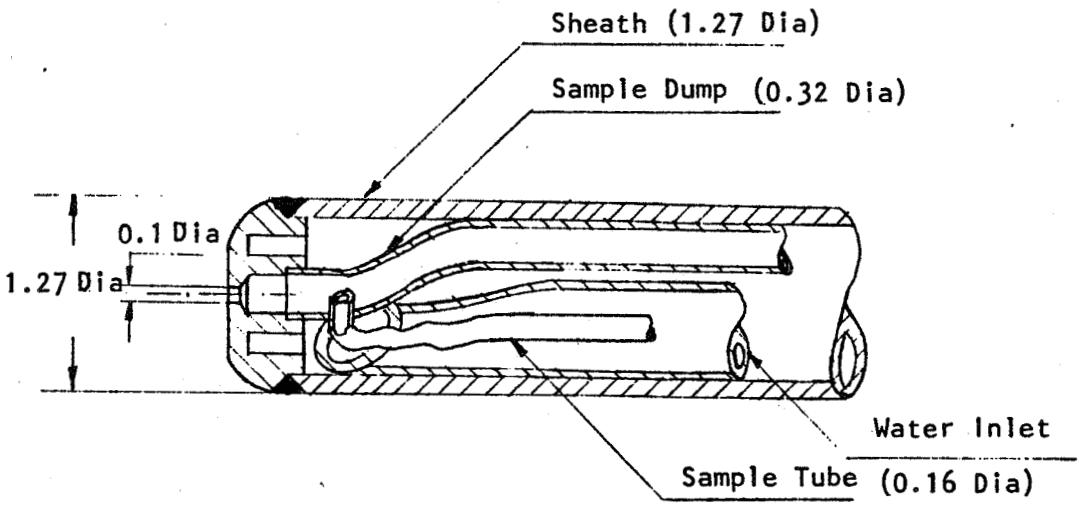


FIGURE 13. PRESSURE/THERMAL-QUENCH PROBE

(Dimensions in cm.)

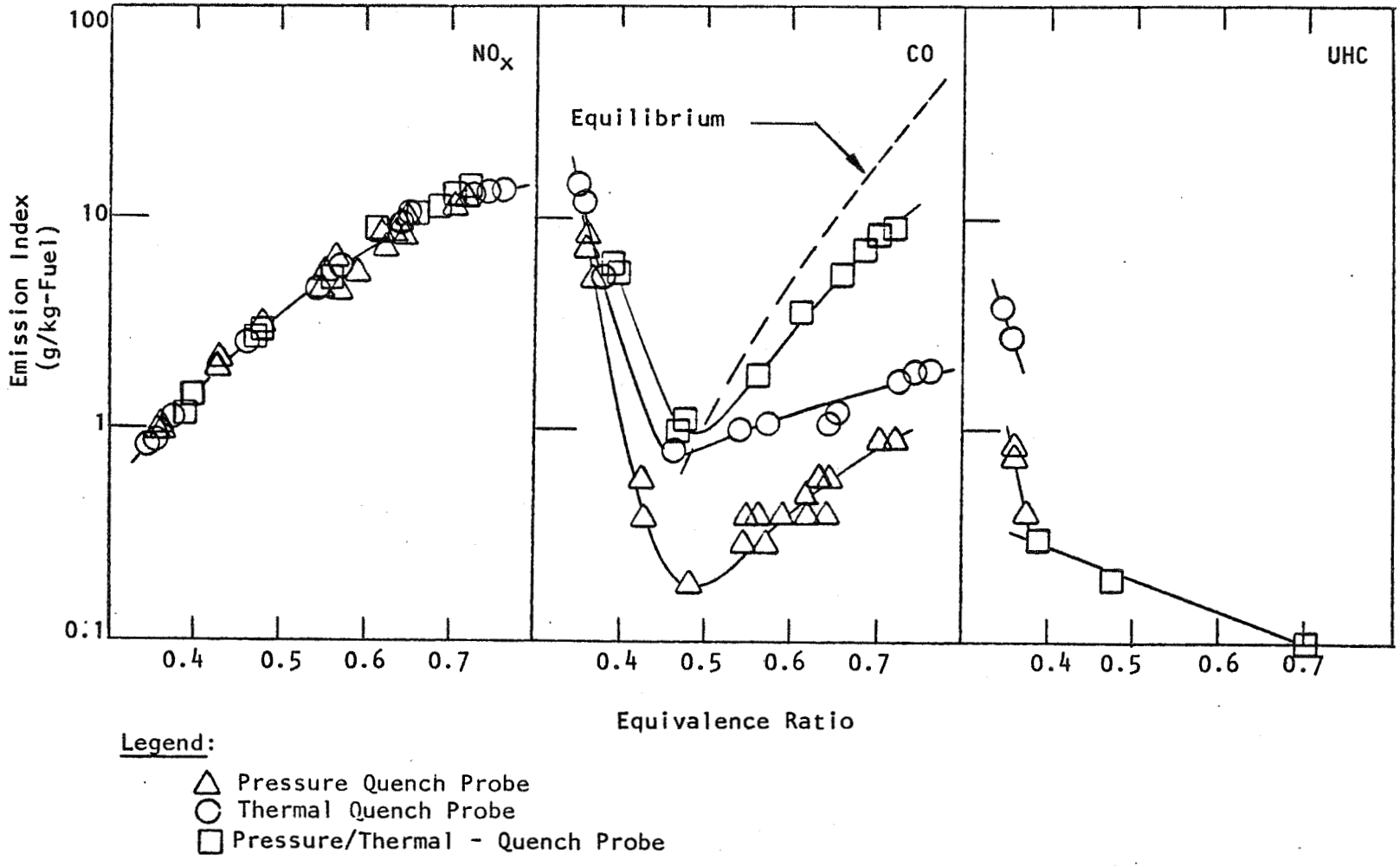


FIGURE 14. COMPARISON OF EMISSIONS MEASUREMENTS USING THERMAL, PRESSURE AND PRESSURE/THERMAL QUENCH PROBE DESIGNS. (T = 800K, p = 10 atm.)

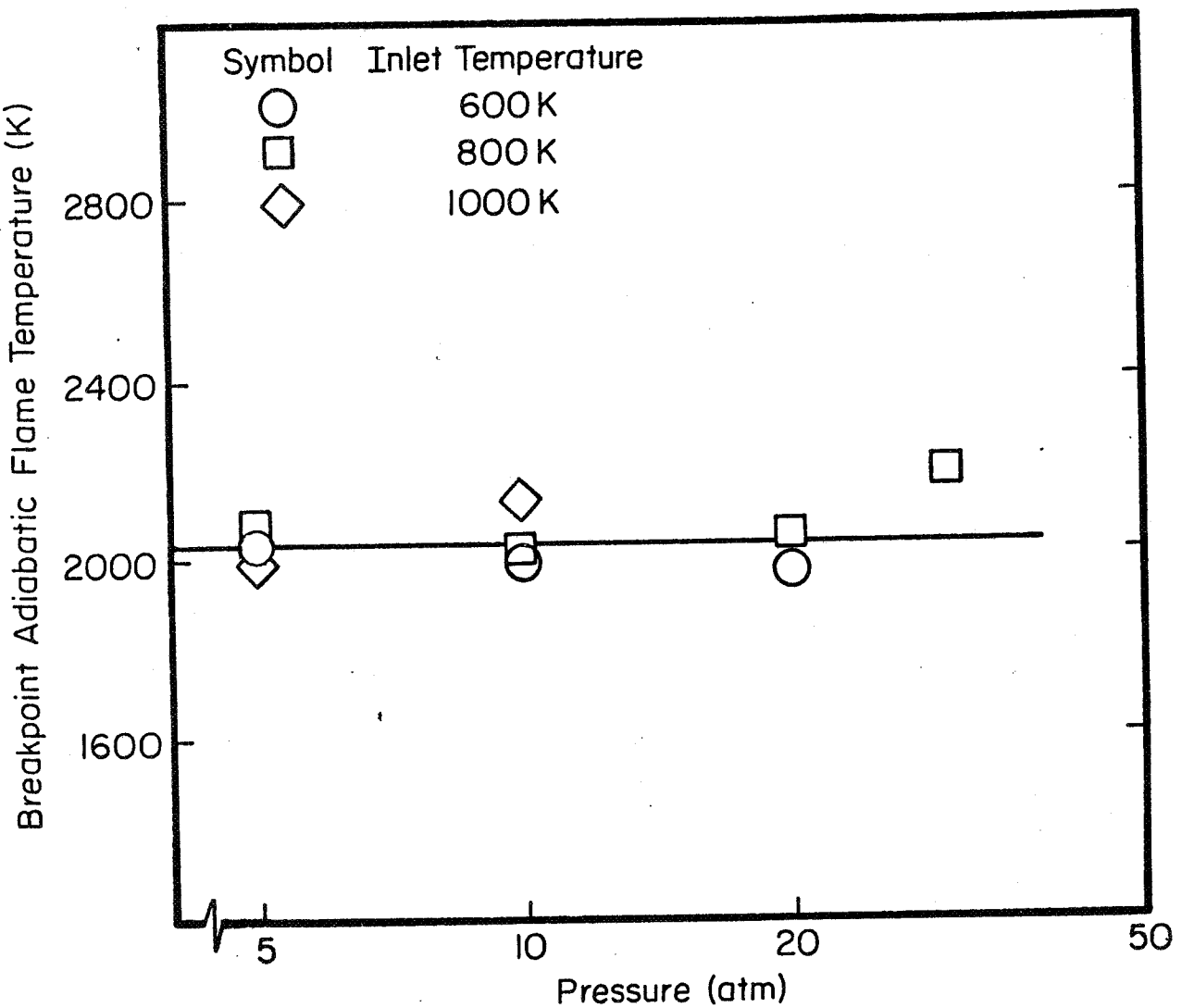


FIGURE 15. ADIABATIC FLAME TEMPERATURE CORRESPONDING TO CO BREAKPOINT AT 2 MSEC RESIDENCE TIME.