Experimental Study of the Effects of Flameholder Geometry on Emissions and Performance of Lean Premixed Combustors

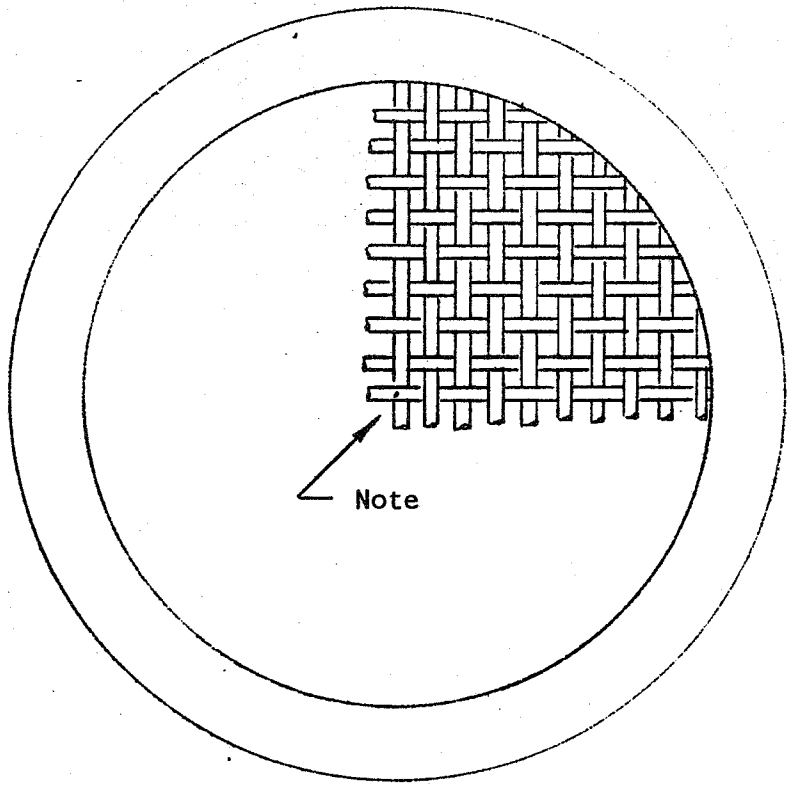
Emission levels and performance of twelve flameholder designs were investigated in a lean, premixed propane-air system at inlet conditions of 800K and 10 atm. The flameholders tested represent six design concepts with two values of blockage for each concept. The design concepts consisted of the following geometries: perforated plate, wire grid, single cone, multiple cone, vee gutter and swirl cone. Measurements were made at reference velocities of 35 m/s, 25 m/s and 20 m/s at combustor stations 10 cm and 30 cm downstream of the flameholder.

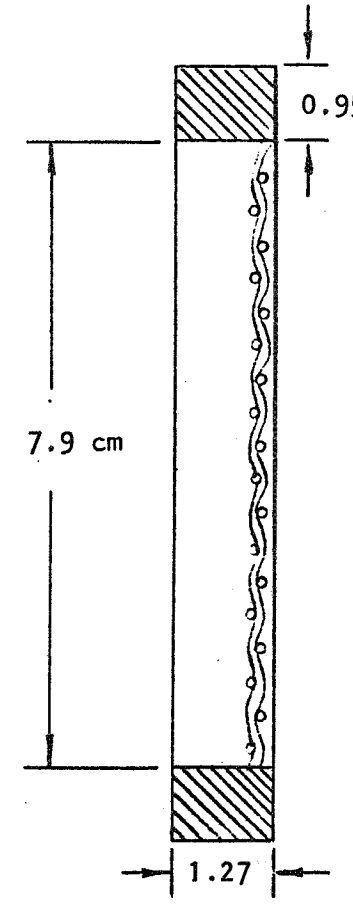
Emissions measurements at a combustor station 30 cm downstream of the flameholder show flameholder pressure drop to be a principal determinant of emissions performance. Increasing pressure drop decreases emissions of NO_x, CO and unburned hydrocarbons. For a given flameholder configuration, increasing blockage increases the pressure drop. It appears that the higher intensity of turbulence in the reaction zone associated with the larger pressure drop designs is responsible for the reduction in the emission levels of all species (NO_x, CO and UHC). The details of flameholder geometry appear to be of second order importance except for their effect on total pressure loss.

Sampling measurements at a station 10 cm downstream of the flameholder display greater sensitivity to the details of design geometry. The vee gutter design, which produces one of the lowest CO and UHC characteristics at the 30 cm station, has a large region of incomplete combustion at the 10 cm combustor station.

The lean stability limit was found to correspond to an equivalence ratio of 0.4 for the 800K/10 atm inlet conditions of this experiment. This limit represents an adiabatic flame temperature of 1700K. Flameholder geometry has no appreciable effect on the lean stability limit.

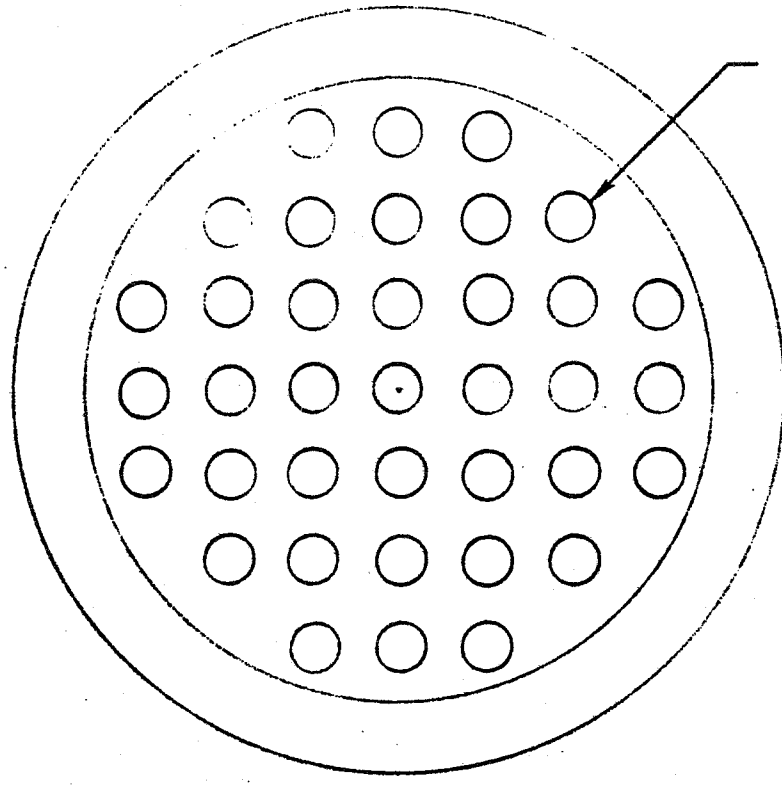
The single and multiple cone flameholder designs which were provided with hollow base cavities suffered burn damage to their downstream surface as reference velocity was reduced. This "burnback" damage occurred without encountering flashback. At an equivalence ratio of 0.7, all incidents of flashback occurred at reference velocities producing maximum components of axial velocity at the flameholder exit station between 30 m/s and 40 m/s. The 70% and 80% blockage perforated plates and the 73% blockage wire grid flameholder did not produce flashback at the lowest velocities (7-9 m/s) at which tests could be conducted.

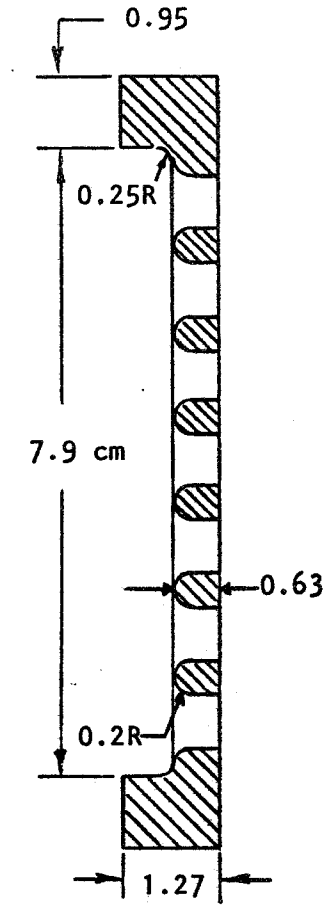




Note: One ply of 0.16 cm (0.20 cm) wire for 60% (73%) blockage. Square grid, 0.42 cm center-to-center spacing

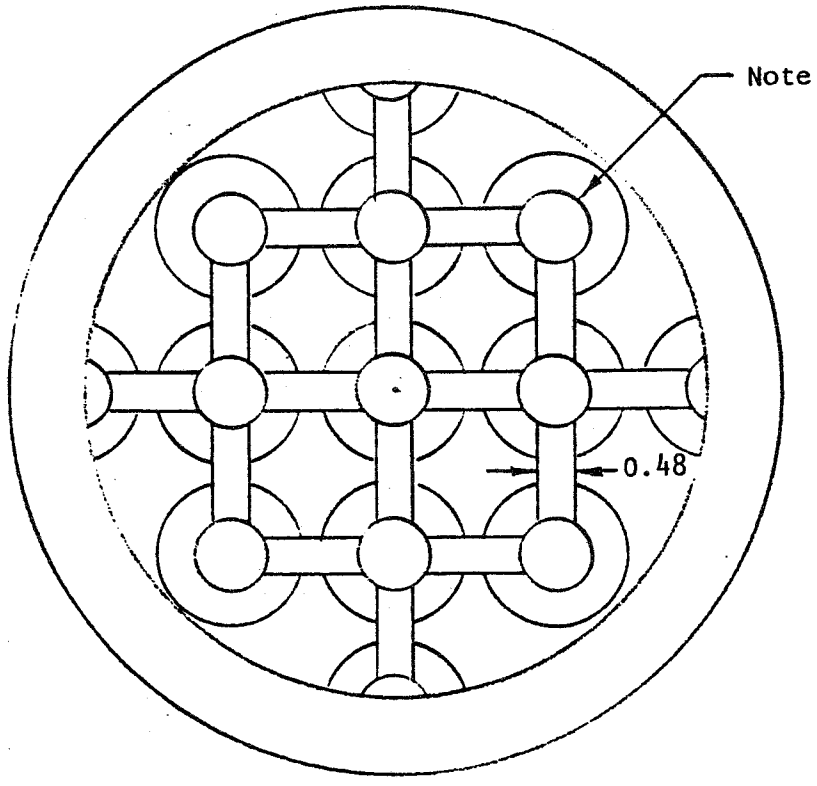
FIGURE 1. WIRE GRID FLAMEHOLDER DETAILS

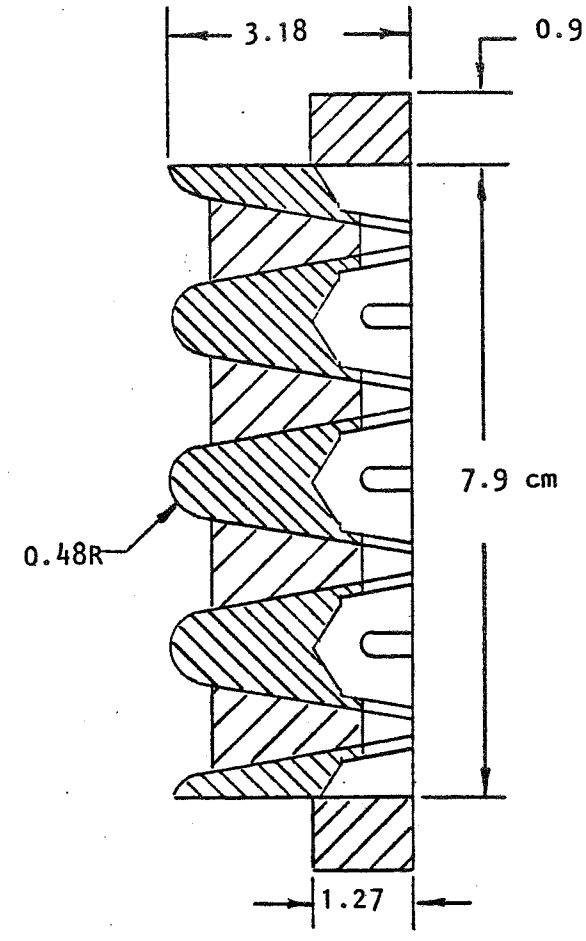




Note: 37 holes on 1.09 x 1.09 grid
Hole dia. 0.71 cm for 70% blockage. Hole dia 0.56 cm for 80% blockage

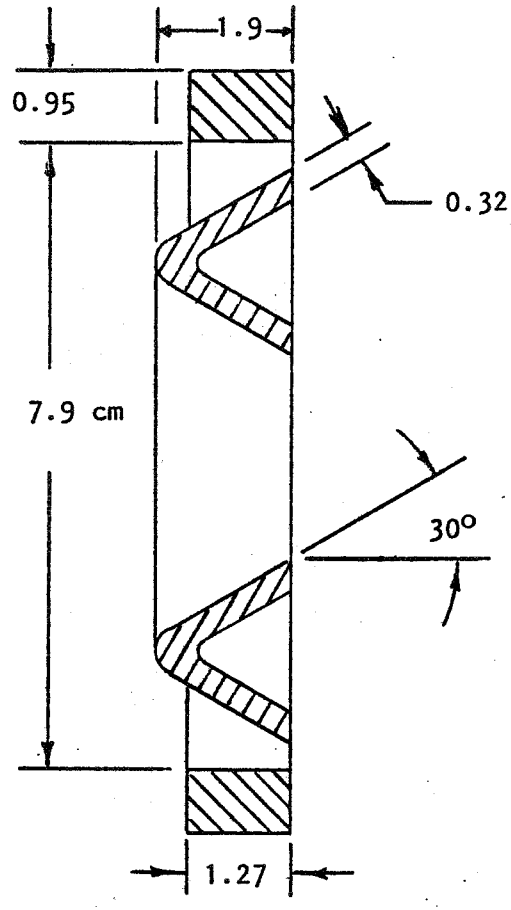
FIGURE 2. PERFORATED PLATE FLAMEHOLDER DETAILS

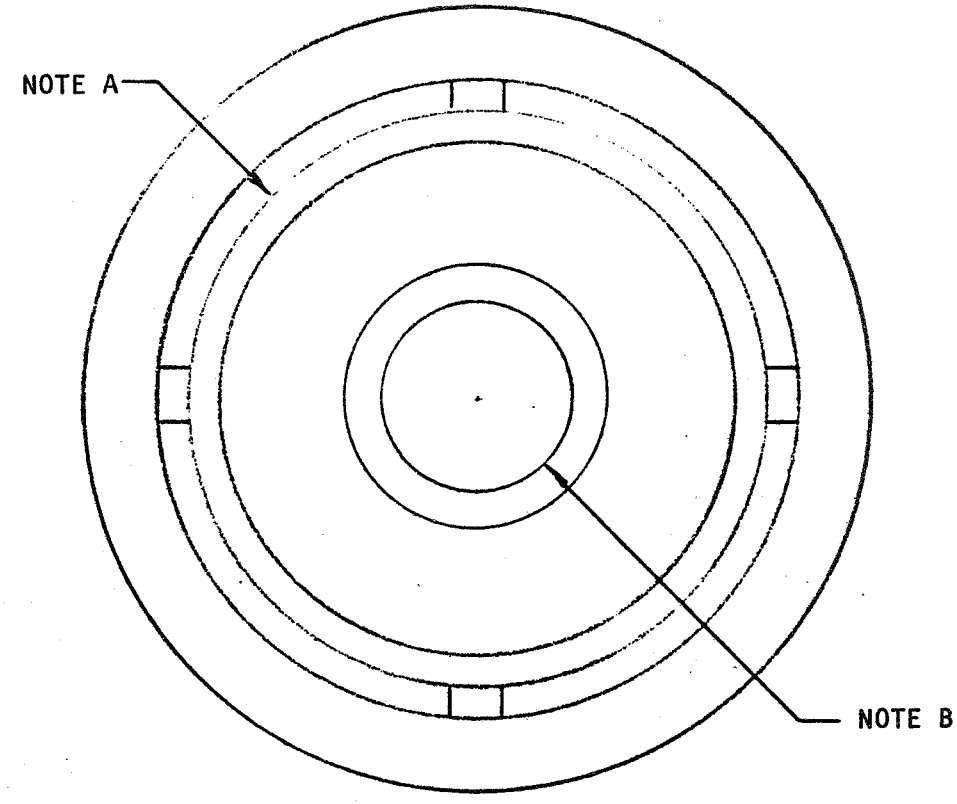




Note: 1.9 cm base diameter,
10^{o} half-angle cones
on 2.1 x 2.1 cm grid

FIGURE 3. Multiple Cone Flameholder Details (70% Blockage)



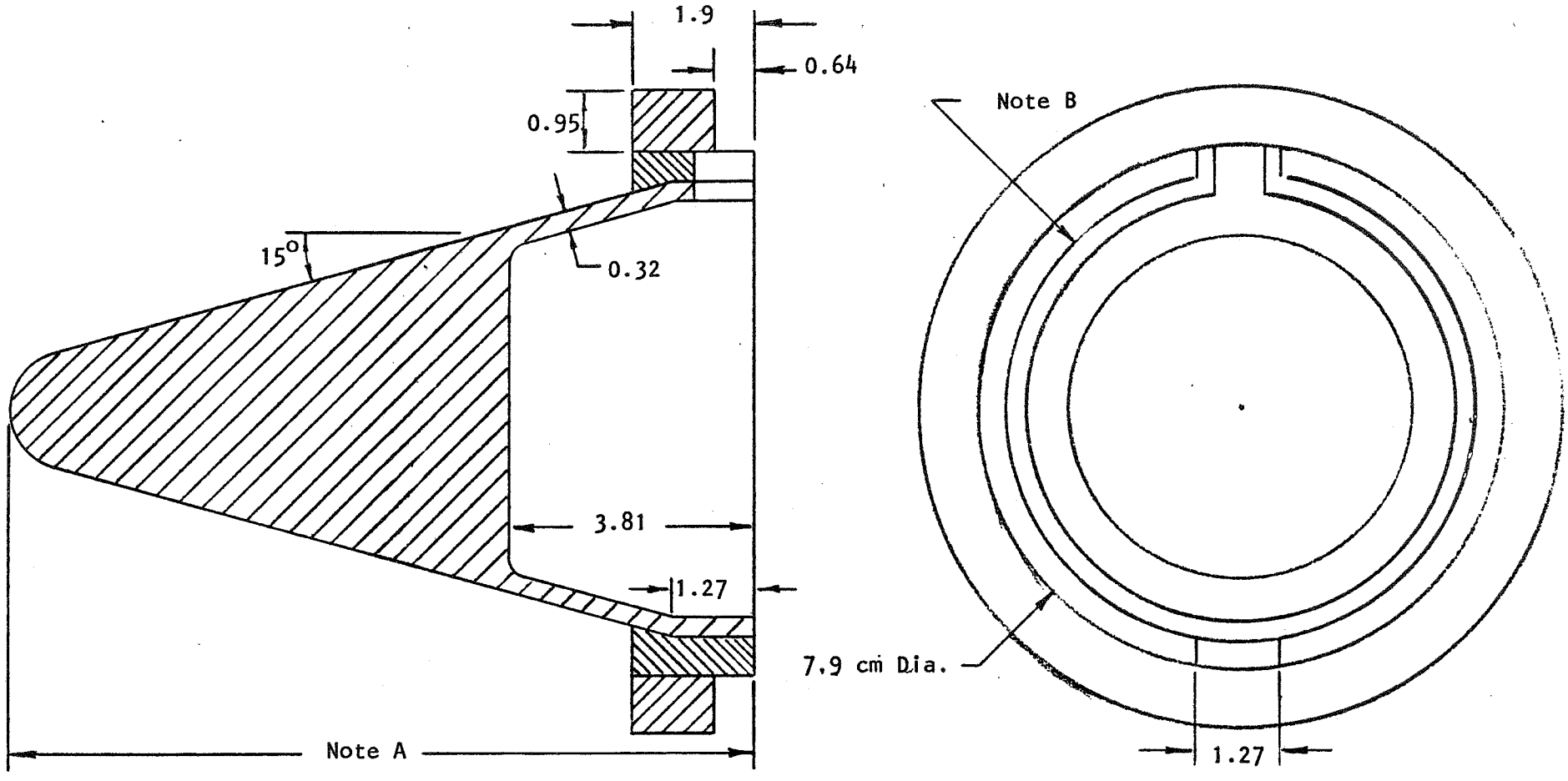


NOTES

A. For 70% blockage, 7.32 cm dia.
   For 80% blockage, 7.52 cm dia.

B. For 70% blockage, 3.05 cm dia.
   For 80% blockage, 2.54 cm dia.

FIGURE 4. VEE GUTTER FLAMEHOLDER DETAILS

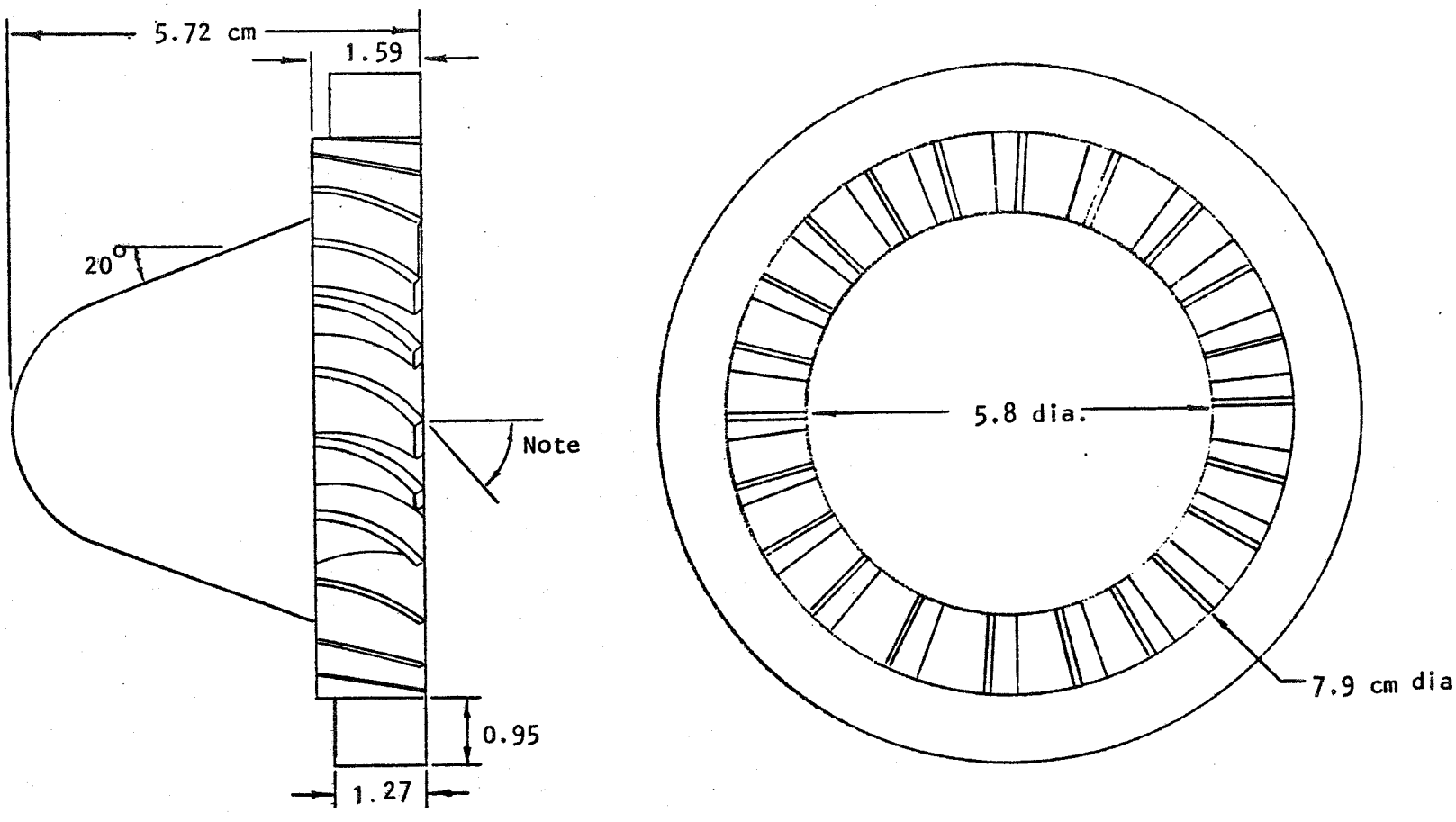


NOTES

A. 11.6 cm for 70% Blockage
   10.5 cm for 80% Blockage

B. 6.35 cm Dia. for 70% Blockage
   7.00 cm Dia. for 80% Blockage

FIGURE 5. SINGLE CONE FLAMEHOLDER DETAILS



Note: 40° for 73% Blockage
50° for 83% Blockage

FIGURE 6. SWIRL FLAMEHOLDER DETAILS

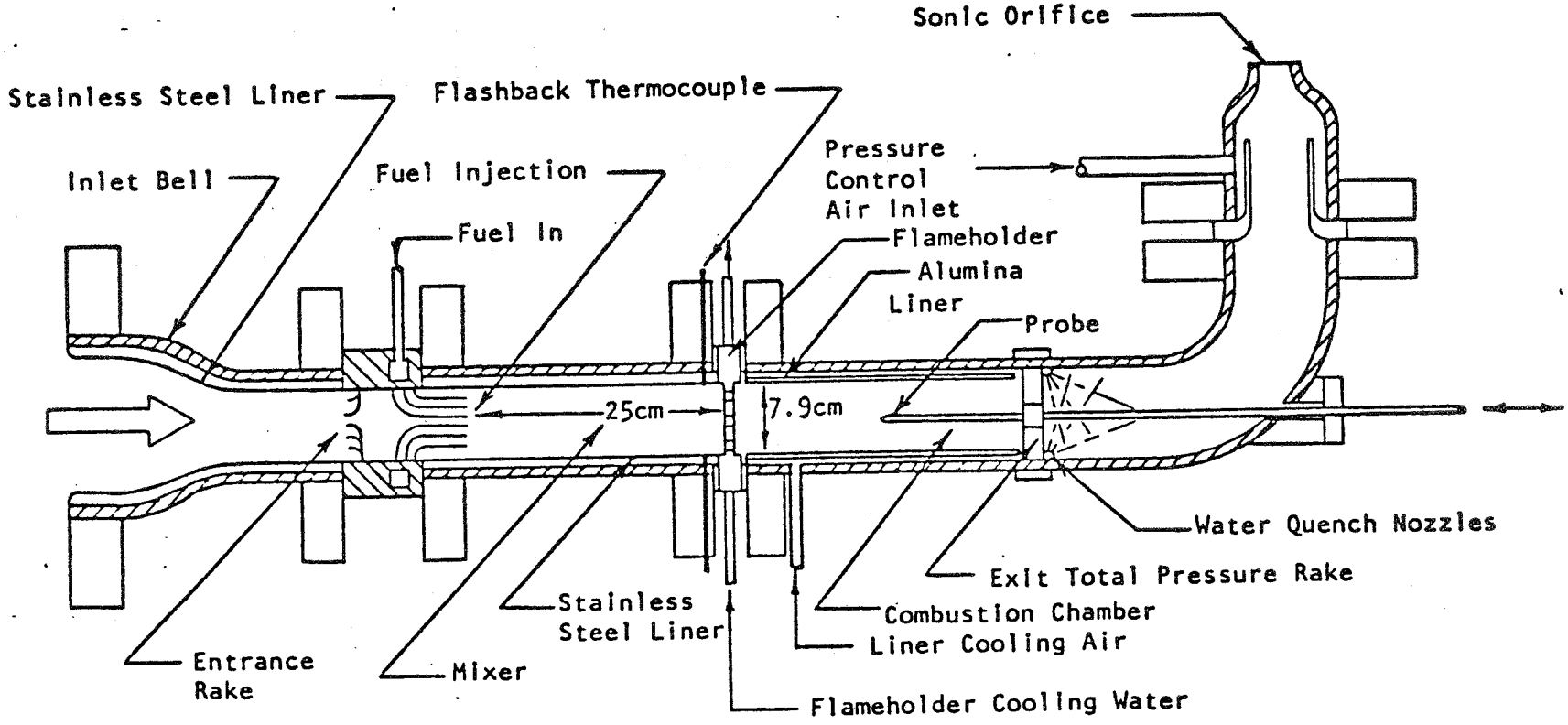


FIGURE 7. COMBUSTION TEST RIG

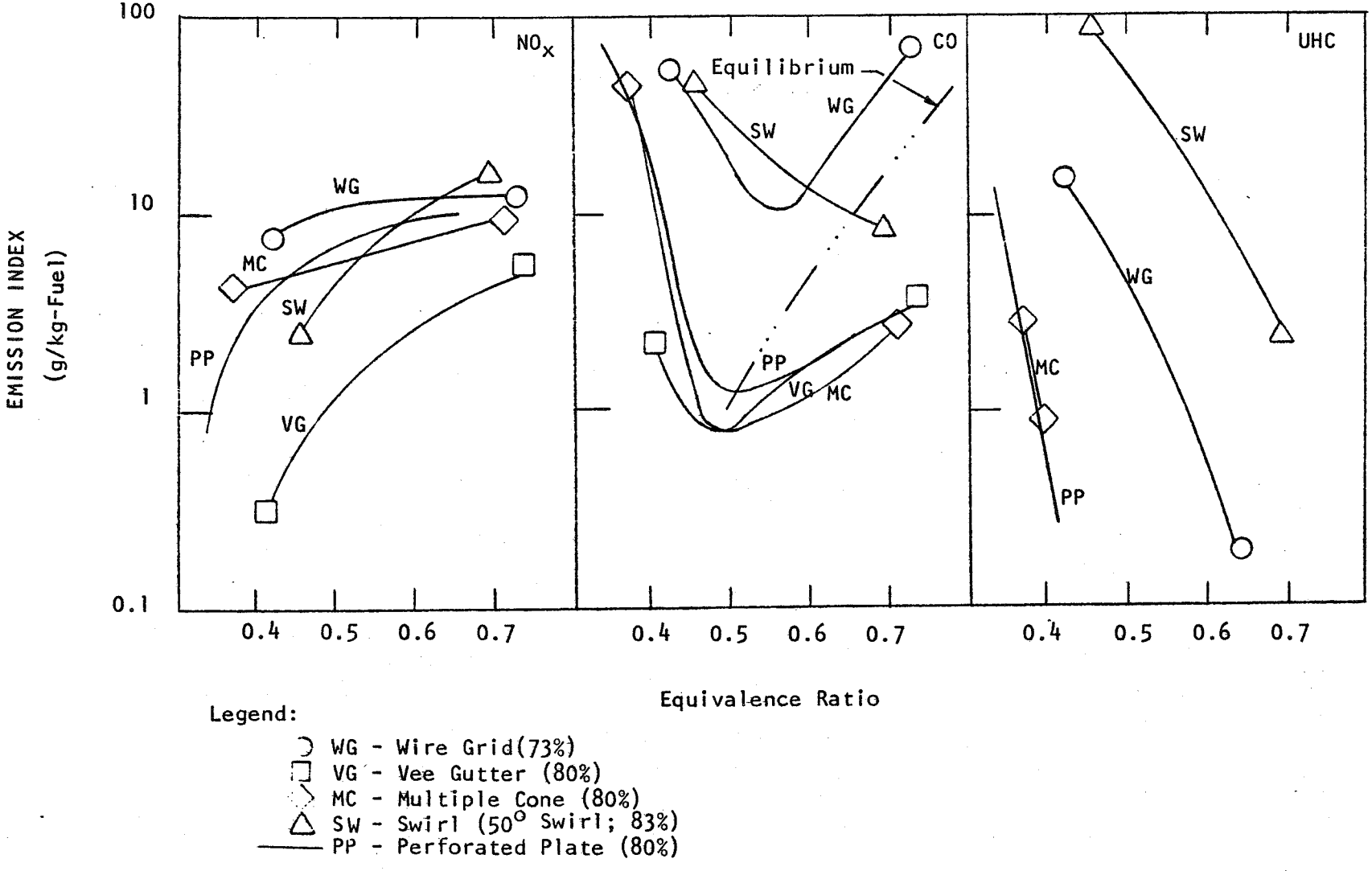
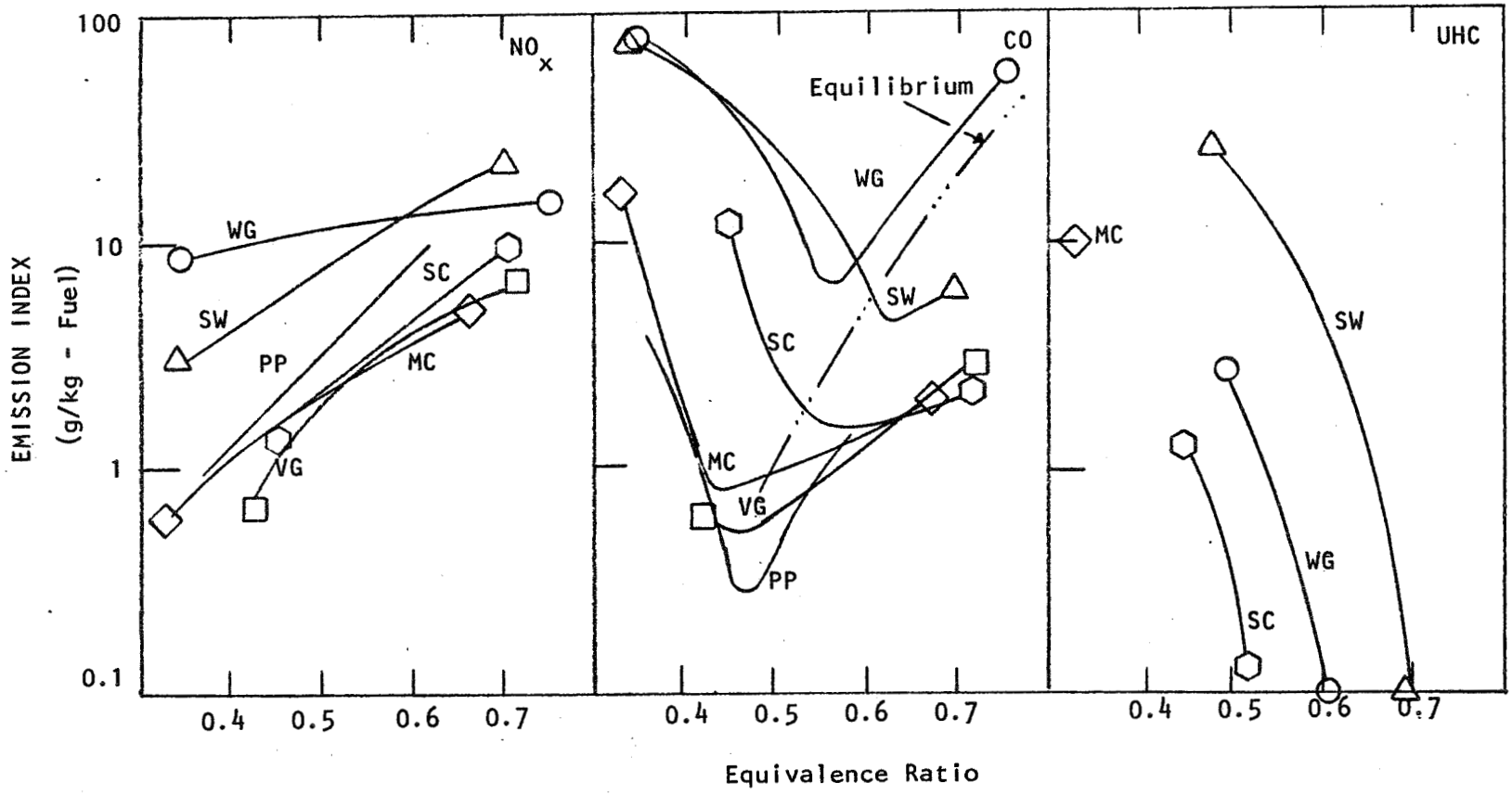


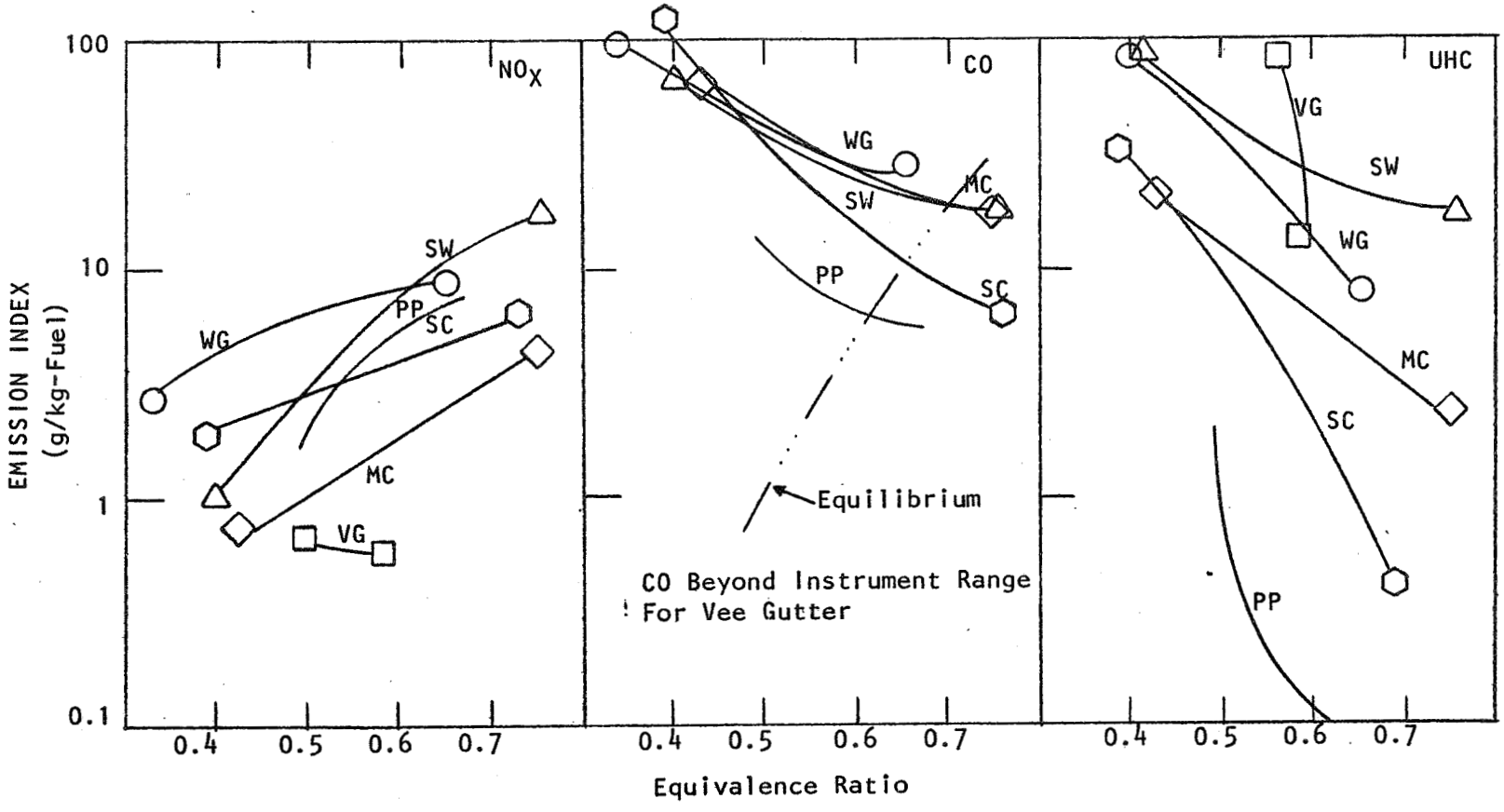
FIGURE 8. COMPARISON OF EMISSION LEVELS FOR HIGH BLOCKAGE FLAMEHOLDERS (V_{ref} = 35 m/s; x = 30 cm)



Legend:

- WG - Wire Grid (73%)
- VG - Vee Gutter (80%)
- MC - Multiple Cone (80%)
- SW - Swirl (50° Swirl, 83%)
- SC - Single Cone (80%)
- PP - Perforated Plate (80%)

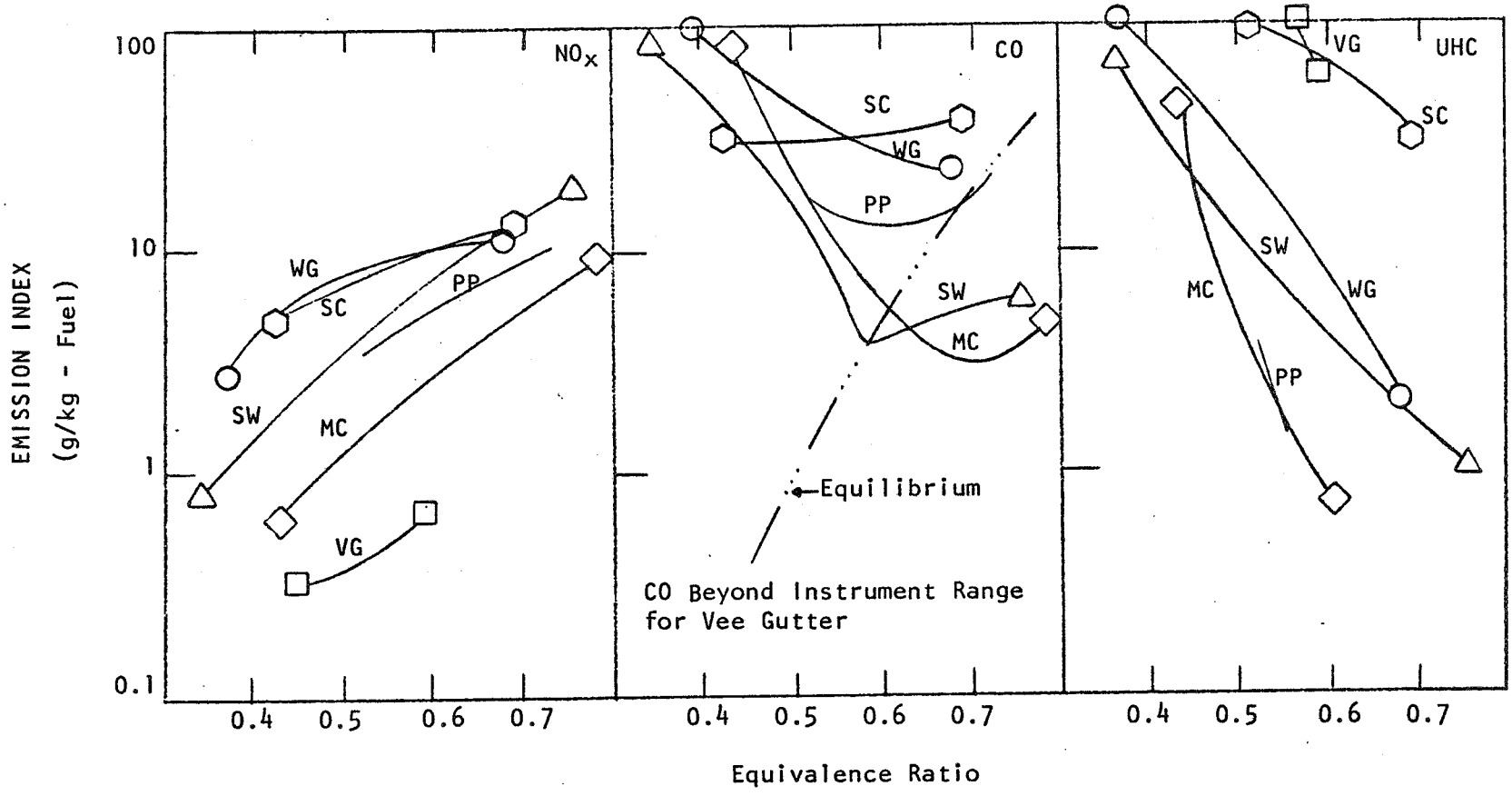
FIGURE 9. COMPARISON OF EMISSION LEVELS FOR HIGH BLOCKAGE FLAMEHOLDERS (V_{ref} = 25 m/s; x = 30 cm)



Legend:

- WG - Wire Grid (73%)
- VG - Vee Gutter (80%)
- MC - Multiple Cone (80%)
- SW - Swirl (50° Swirl; 83%)
- SC - Single Cone (80%)
- PP - Perforated Plate (80%)

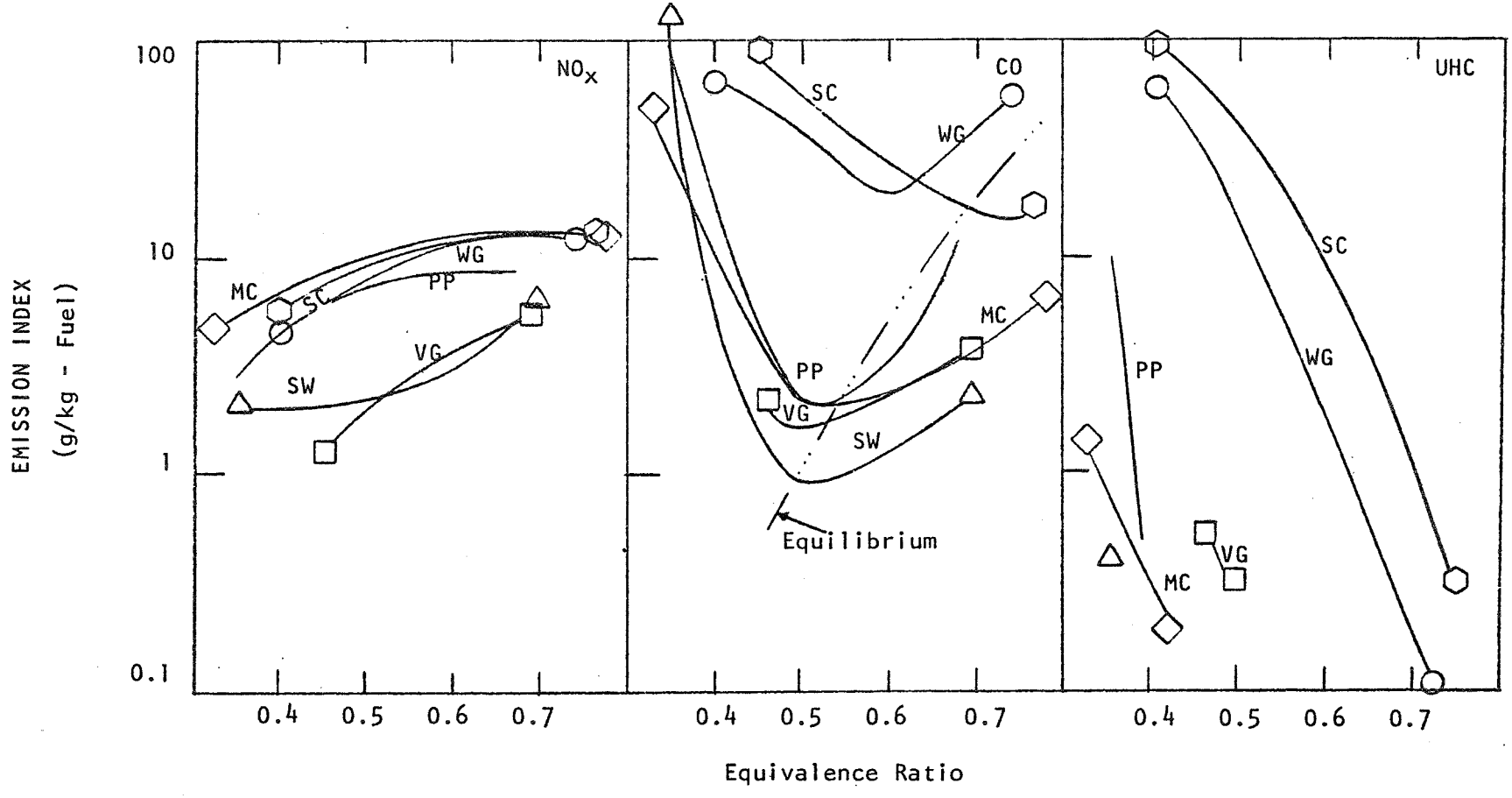
FIGURE 10. COMPARISON OF EMISSION LEVELS FOR HIGH BLOCKAGE FLAMEHOLDER (V_{ref}=25 m/s; x = 10 cm)



Legend:

- WG - Wire Grid (73%)
- VG - Vee Gutter (80%)
- MC - Multiple Cone (80%)
- SW - Swirl (50° Swirl; 83%)
- SC - Single Cone (80%)
- PP - Perforated Plate (80%)

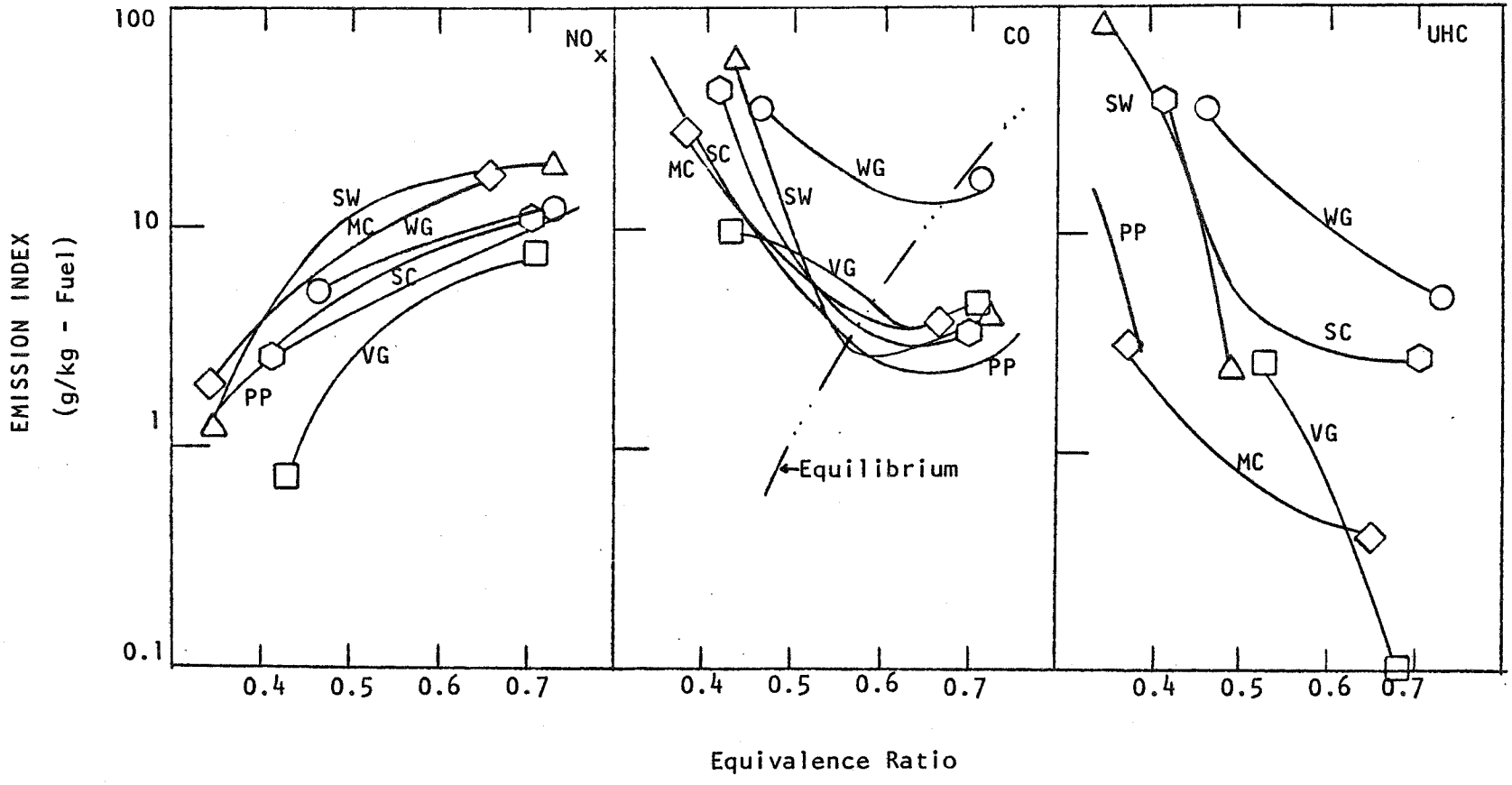
FIGURE 11. COMPARISON OF EMISSION LEVELS FOR HIGH BLOCKAGE FLAMEHOLDERS (V_{ref} = 20 m/s; x = 10 cm)



Legend:

- WG - Wire Grid (60%)
- VG - Vee Gutter (70%)
- MC - Multiple Cone (70%)
- SW - Swirl (40° Swirl; 73%)
- SC - Single Cone (70%)
- PP - Perforated Plate (70%)

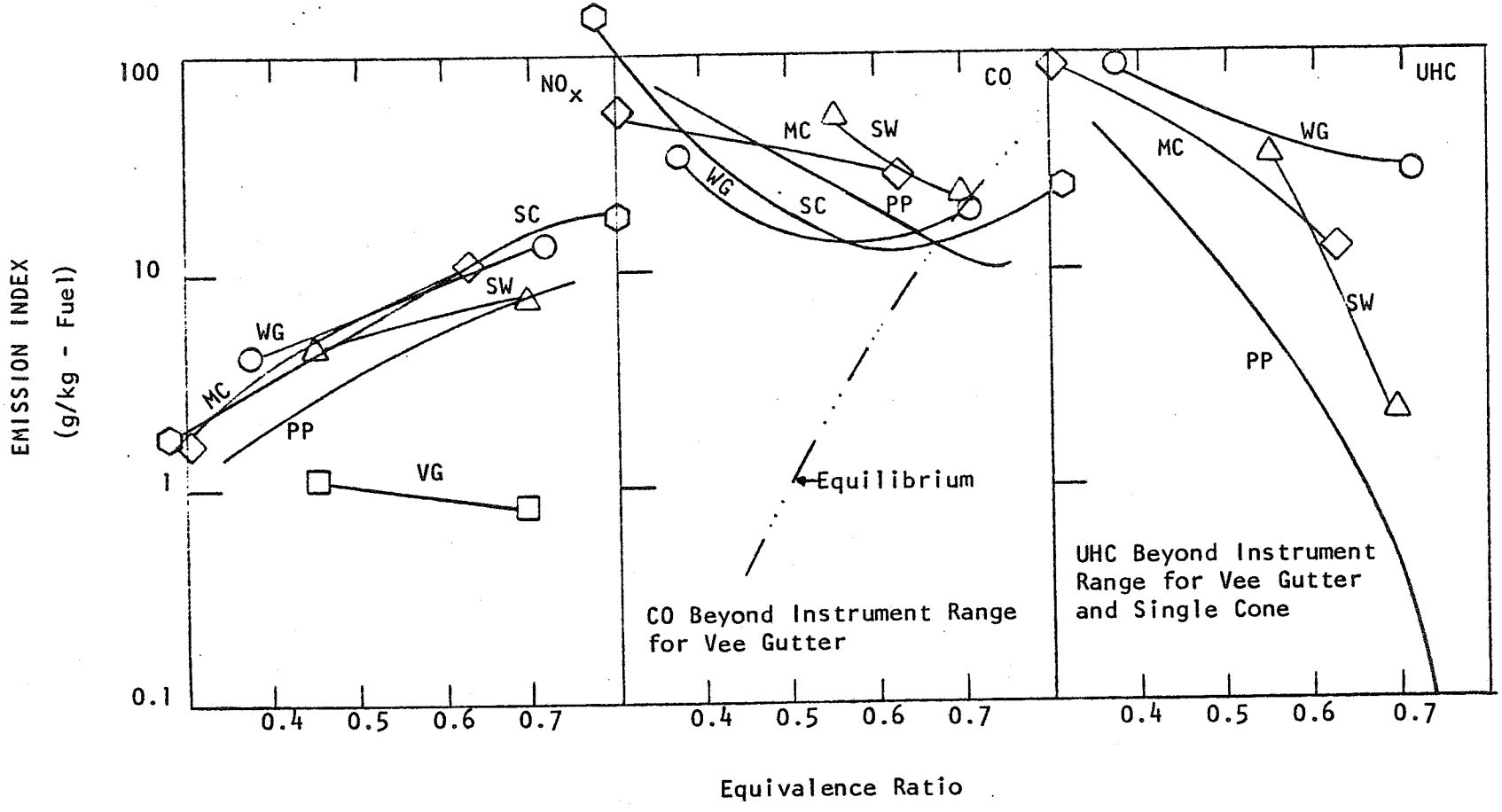
FIGURE 12. COMPARISON OF EMISSION LEVELS FOR LOW BLOCKAGE FLAMEHOLDER (V_{ref} = 35 m/s; x = 30 cm)



Legend:

- WG - Wire Grid (60%)
- VG - Vee Gutter (70%)
- MC - Multiple Cone (70%)
- SW - Swirl (40° Swirl; 73%)
- SC - Single Cone (70%)
- PP - Perforated Plate (70%)

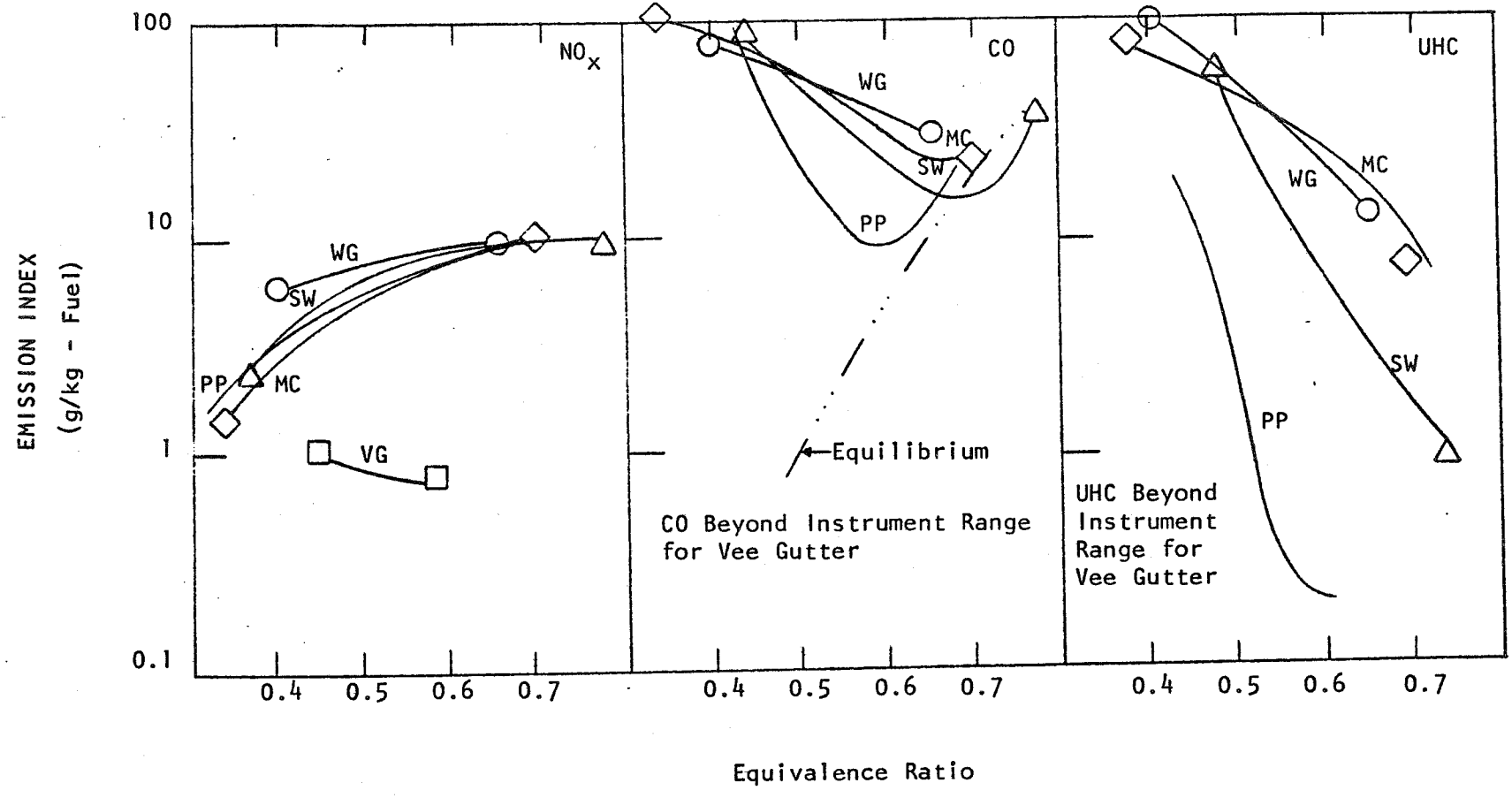
FIGURE 13. COMPARISON OF EMISSION LEVELS FOR LOW BLOCKAGE FLAMEHOLDERS (V_{ref} = 25 m/s; x = 30 cm)



Legend:

- WG - Wire Grid (60%)
- VG - Vee Gutter (70%)
- MC - Multiple Cone (70%)
- SW - Swirl (40° Swirl; 73%)
- SC - Single Cone (70%)
- PP - Perforated Plate (70%)

FIGURE 14. COMPARISON OF EMISSION LEVELS FOR LOW BLOCKAGE FLAMEHOLDERS (V_{ref} = 25 m/s; x = 10 cm)



Legend:

- WG - Wire Grid (60%)
- VG - Vee Gutter (70%)
- MC - Multiple Cone (70%)
- SW - Swirl (40° Swirl; 73%)
- PP - Perforated Plate (70%)

FIGURE 15. COMPARISON OF EMISSION LEVELS FOR LOW BLOCKAGE FLAMEHOLDERS (V_{ref} = 20 m/s; x = 10 cm)

TABLE I

SUMMARY OF FLAMEHOLDER CHARACTERISTICS

TYPE	BLOCKAGE	BLOCKAGE DEPTH	IGNITION PERIMETER	IGNITION WIDTH	CHAR. WAKE DIMENSION	DESCRIPTION
Wire Grid	60%	0.16cm	300cm	0.27cm	0.16cm	0.16cm dia. wire - 0.42cm wire spacing
	73%	0.20cm	230cm	0.22cm	0.20cm	0.20cm dia. wire - 0.42cm wire spacing
Perforated Plate	70%	0.64cm	83cm	0.71cm	0.84cm	37 holes - 0.71cm dia.
	80%	0.64cm	65cm	0.56cm	0.99cm	37 holes - 0.56cm dia.
Multiple Cone	70%	3.2cm*	71cm	1.03cm	1.9cm	1.9cm base dia. cones - 2.1cm spacing
	80%	3.2cm*	102cm	0.79cm	1.9cm	1.9cm base dia. cones - 1.9cm spacing
Vee Gutter	70%	1.9cm*	33cm	3.05cm	2.1cm	30° half angle - 2.88cm OD annulus
	80%	1.9cm*	32cm	2.54cm	2.5cm	30° half angle - 2.96cm OD annulus
Single Cone	70%	10.5cm*	20cm	0.79cm	6.4cm	15° half angle - 6.35cm dia. hollow base
	80%	11.6cm*	22cm	0.48cm	7.0cm	15° half angle - 7.00cm dia. hollow base
Swirl	73%	1.8cm	18cm	1.07cm	12.0cm	40° turning vanes - hub/tip ratio 0.73
	83%	1.8cm	18cm	1.07cm	20.0cm	50° turning vanes - hub/tip ratio 0.73

*Blockage varies across this distance attaining full value only at exit plane.

TABLE II

FLAMEHOLDER PRESSURE DROP SUMMARY

GEOMETRY	BLOCKAGE (%)	RESISTANCE COEFFICIENT k	$\frac{\Delta p}{P_T}$ (% at V_{ref} = 25 m/s)
Wire Grid	60	1.0	0.8
Wire Grid	73		2.1
Perforated Plate	70	1.6	2.5
Perforated Plate	80		5.8
Multiple Cone	70	1.5	2.3
Multiple Cone	80		5.4
Vee Gutter	70	2.2	3.3
Vee Gutter	80		7.1
Single Cone	70	1.5	2.3
Single Cone	80		5.4
40^{o} Swirl	73	1.8	3.4
50^{o} Swirl	83	0.9	4.8

TABLE III

LEAN STABILITY LIMIT

GEOMETRY	BLOCKAGE (%)	V_r=20m/s LSL	V_r=25m/s LSL	V_r=35m/s LSL
Wire Grid	60	<.40	.35	<.42
Wire Grid	73	<.37	.32	.38
Perforated Plate	70	.30	.35	<.30
Perforated Plate	80	<.48	.35*	.32
Multiple Cone	70	.32	.29	.24
Multiple Cone	80	.38	.32**	.30
Vee Gutter	70	.44	.42	.44
Vee Gutter	80	.44	.35	.41
Single Cone	70	--	.28	.32
Single Cone	80	<.42	.38	--
40° Swirl	73	.32	.32	.33
50° Swirl	83	.30	.30	.34

*On one test, 0.45

**On one test, 0.42

TABLE IV

FLAMEHOLDER FLASHBACK/BURNBACK SUMMARY

GEOMETRY	BLOCKAGE (%)	MODE	$\dot{V}_{ref}$ (m/s)	$V_{max\text{-}axial}$ (m/s)
Wire Grid	60	Flashback	14	35
	73	No Failure	<9	<33
Perforated Plate	70	No Failure	<7	<23
	80	No Failure	<8	<40
Vee Gutter	70	Flashback	9	30
	80	Not Tested		
40^{o} Swirl	73	Flashback	11	31
50^{o} Swirl	83	Flashback	10	38
Single Cone	70	Burnback	20	67
	80	Burnback	20	100
Multiple Cone	70	Burnback	18	60
	80	Burnback	7	35