IN: Yang, J.C., et al., Editors, Solid Propellant Gas Generators: Proceedings of the 1995 Workshop, NISTIR 5766, June 28-29, 1995, 123-146 pp, 1995

ASPECTS OF FLAME SUPPRESSION

Anthony Hamins

Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, Maryland 20899

OBJECTIVE

Give guidance on the performance of fire suppression systems in engine nacelles.

Compare Effectiveness of 3 Key Agents

Formula	Designation	IUPAC Name
CF_3I	-	iodotrifluoromethane
C_2HF_5	HFC-125	pentafluoroethane
C_3HF_7	HFC-227ea	heptafluoropropane

Testing Solid Propellant Gas Generators

1. What are key parameters controlling flame extinction?

   Flow Velocity

   Air Temperature

   Pressure

   baffle height

   Agent

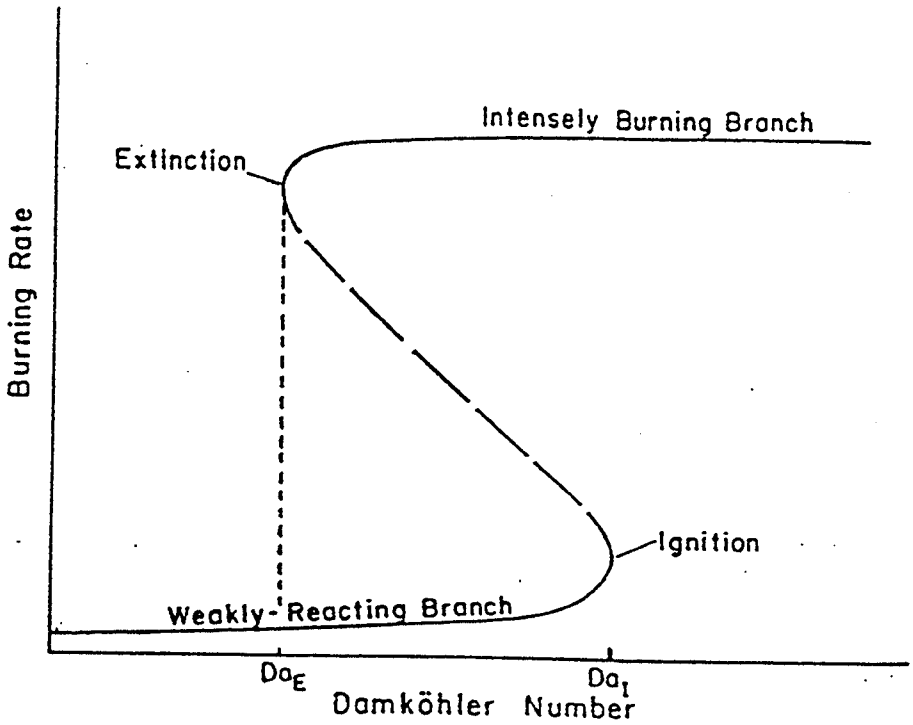
   Fuel

2. What is an appropriate test apparatus?

ASPECTS OF FLAME SUPPRESSION

Suppression Tests

Experiment	Flow Configuration	Type of Combustion	Flow Field
cup burner	coflow	non-premixed	quasi-laminar
opposed flow diffusion flame	counterflow	non-premixed	laminar
baffle stabilized spray flame	obstacle in middle of field	recirculation zone	turbulent
baffle stabilized pool fire	obstacle against wall	recirculation zone	turbulent

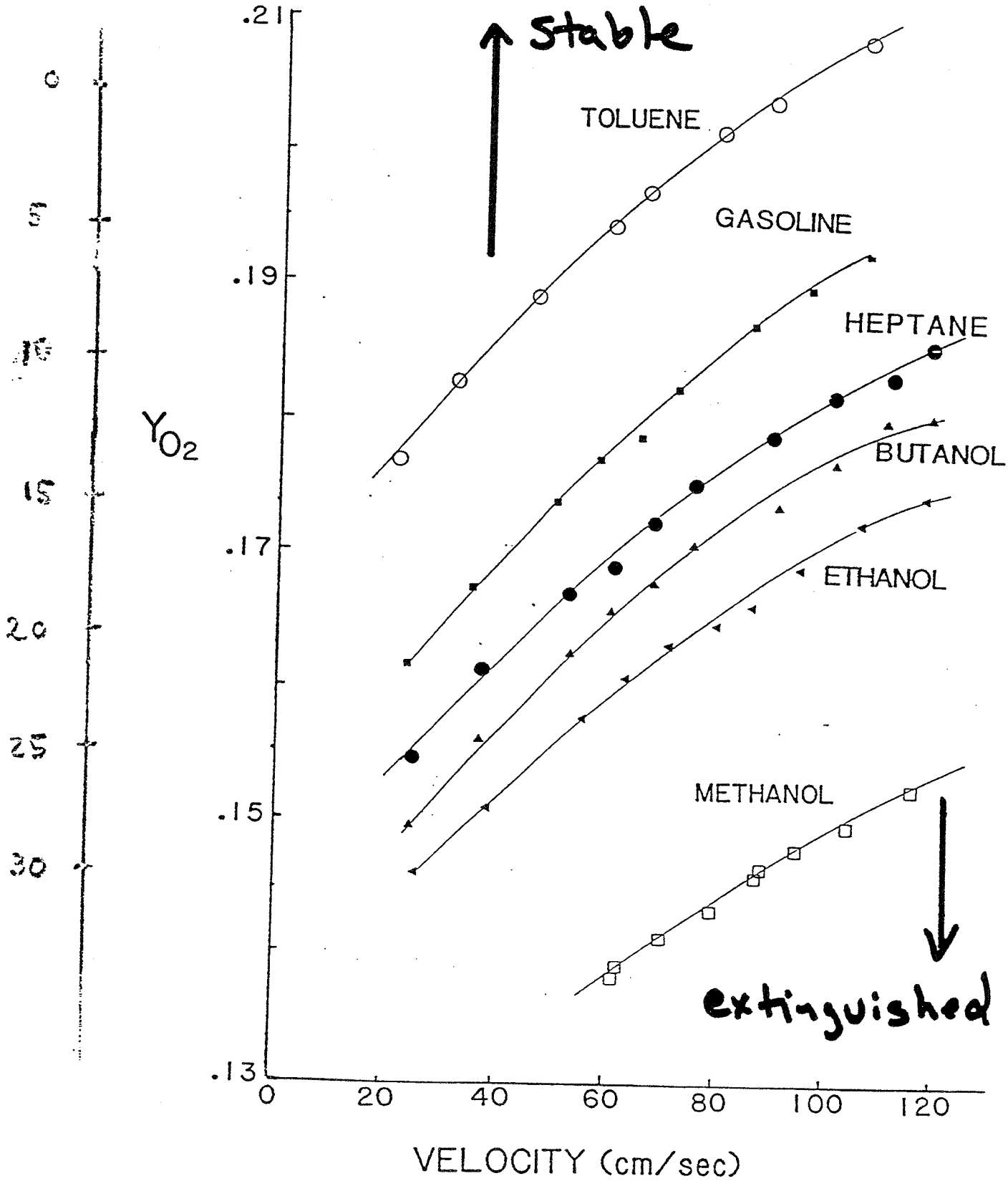


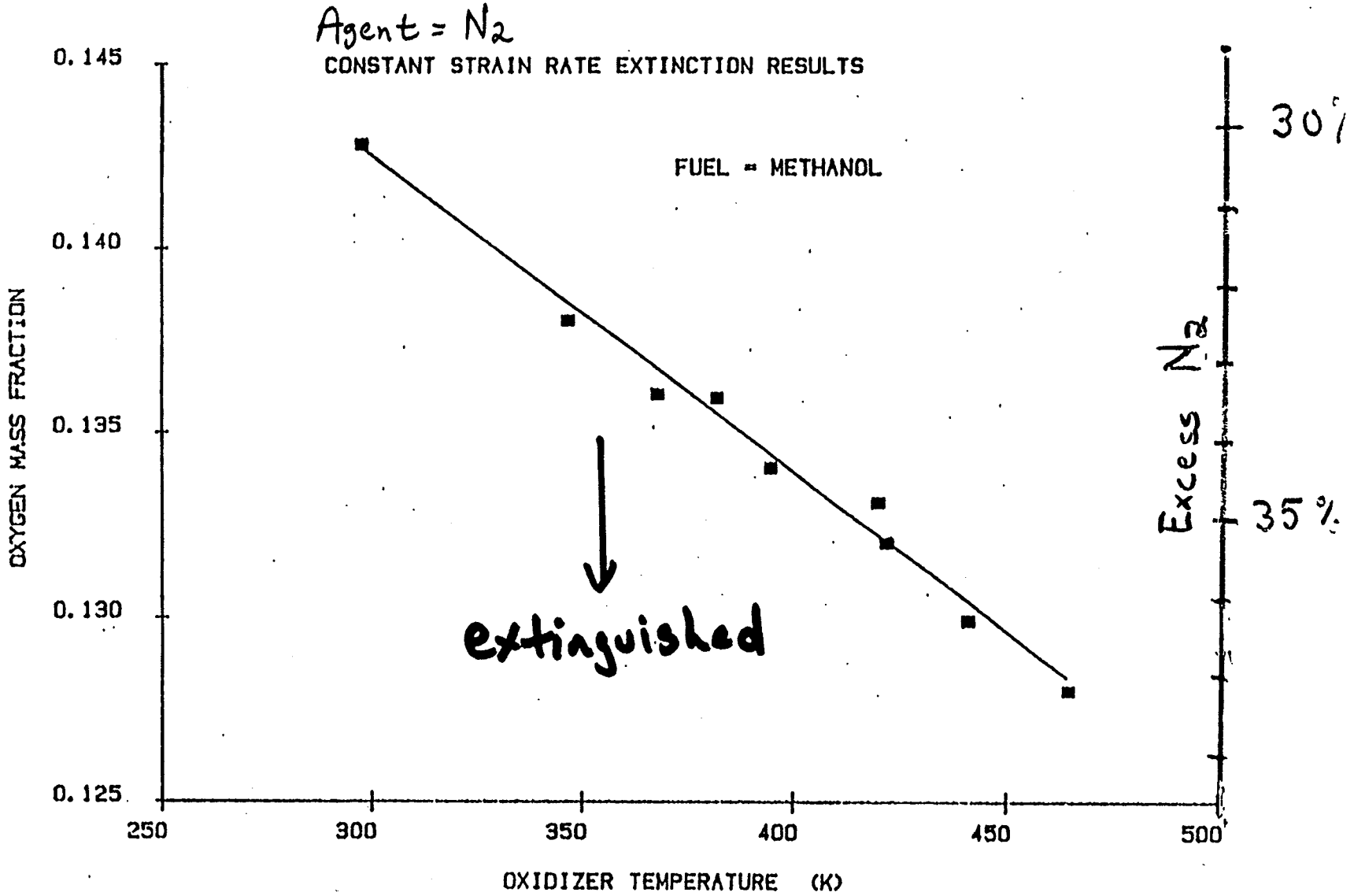
$$Da = \tau_F / \tau_{CR} = \text{Flow Time} / \text{Chemical Reaction Time}$$

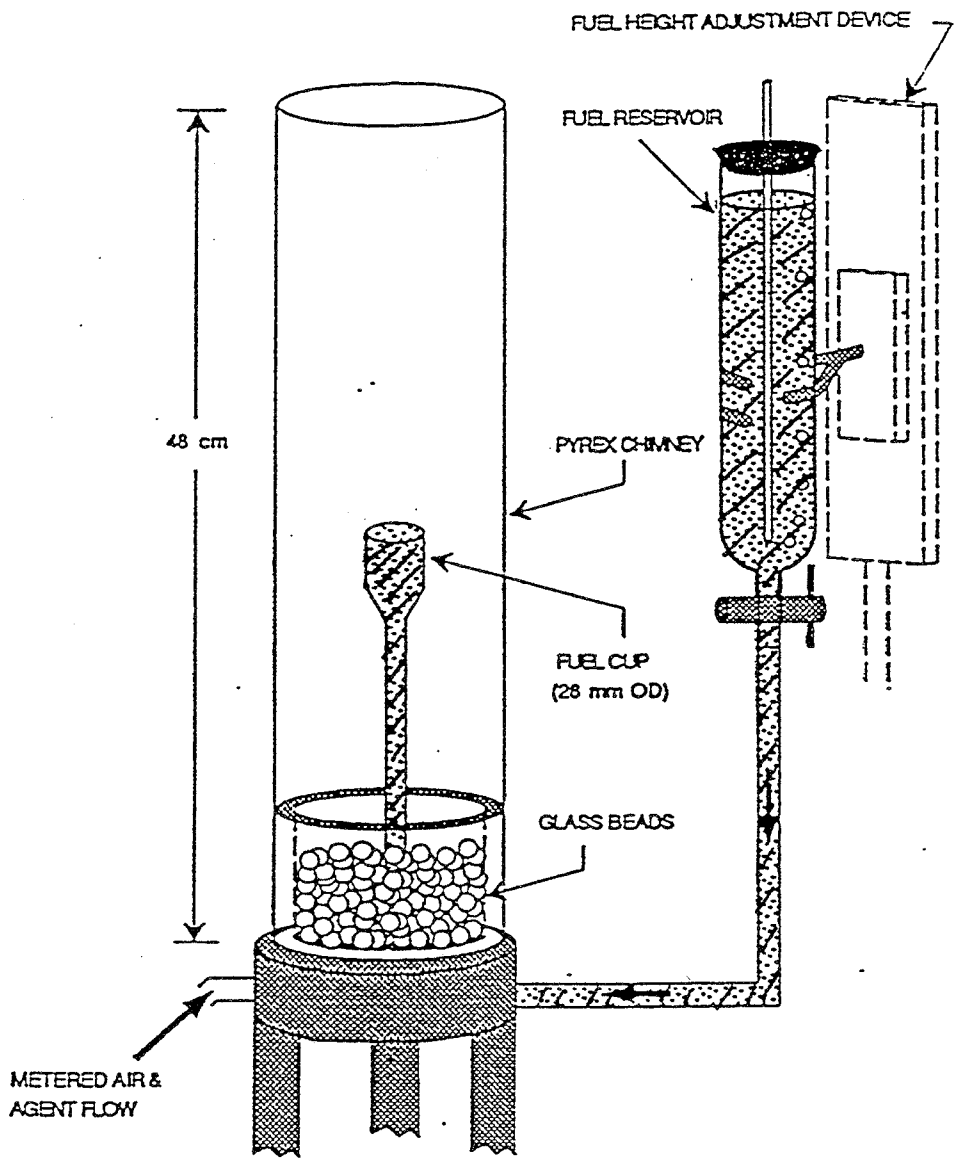
$$\tau_F \propto 1/(\text{Velocity Gradient}) = 1/(U/L)$$

$$\tau_{CR} \propto 1/(\text{Rate Constant}) = 1/(B \cdot \exp[-E/RT])$$

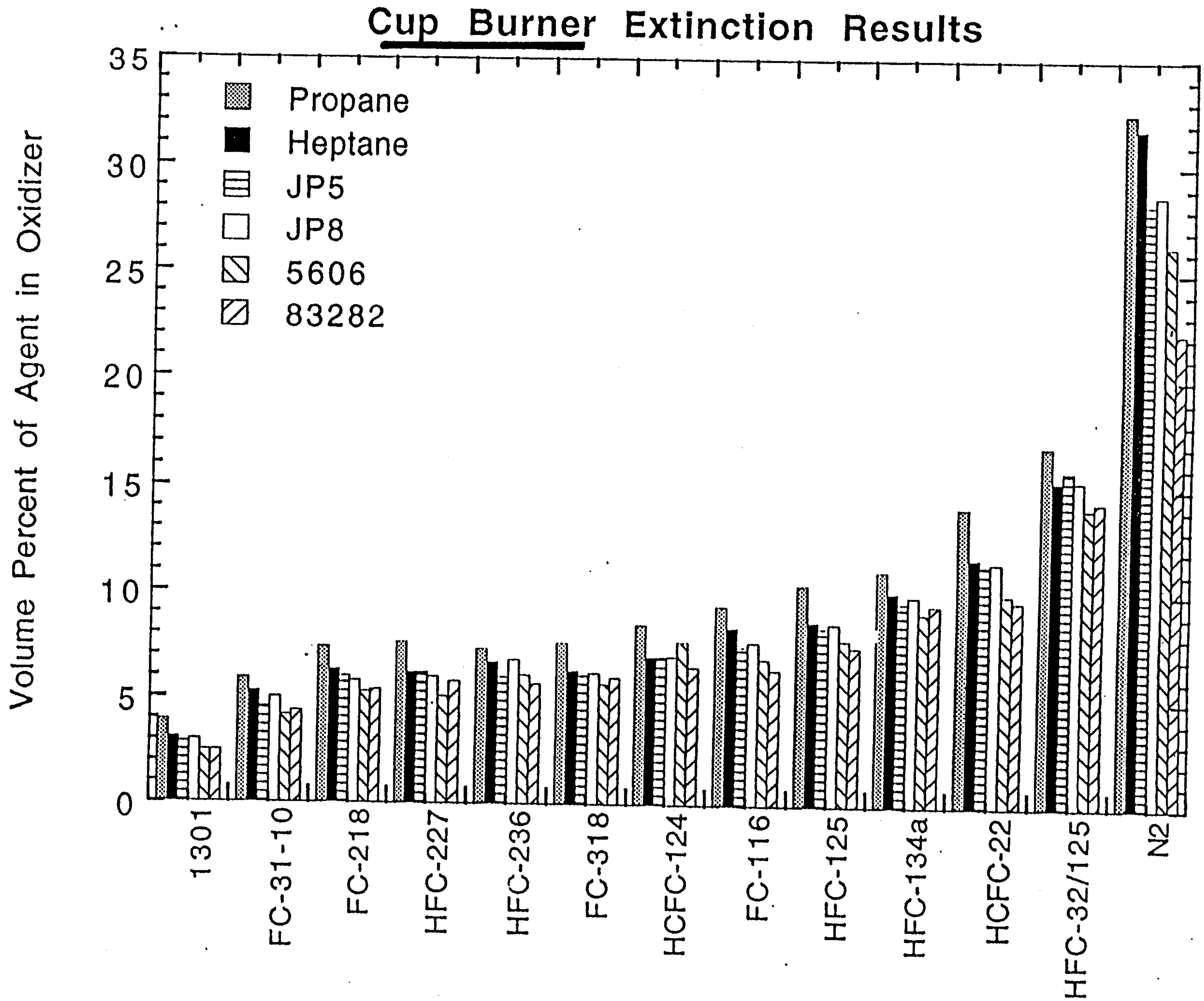
Excess N$_2$


Stable
TOLUENE
GASOLINE
HEPTANE
BUTANOL
ETHANOL
METHANOL
extinguished
Y_{O_2}
.21
.19
.17
.15
.13
0
5
10
15
20
25
30
0
20
40
60
80
100
120
VELOCITY (cm/sec)

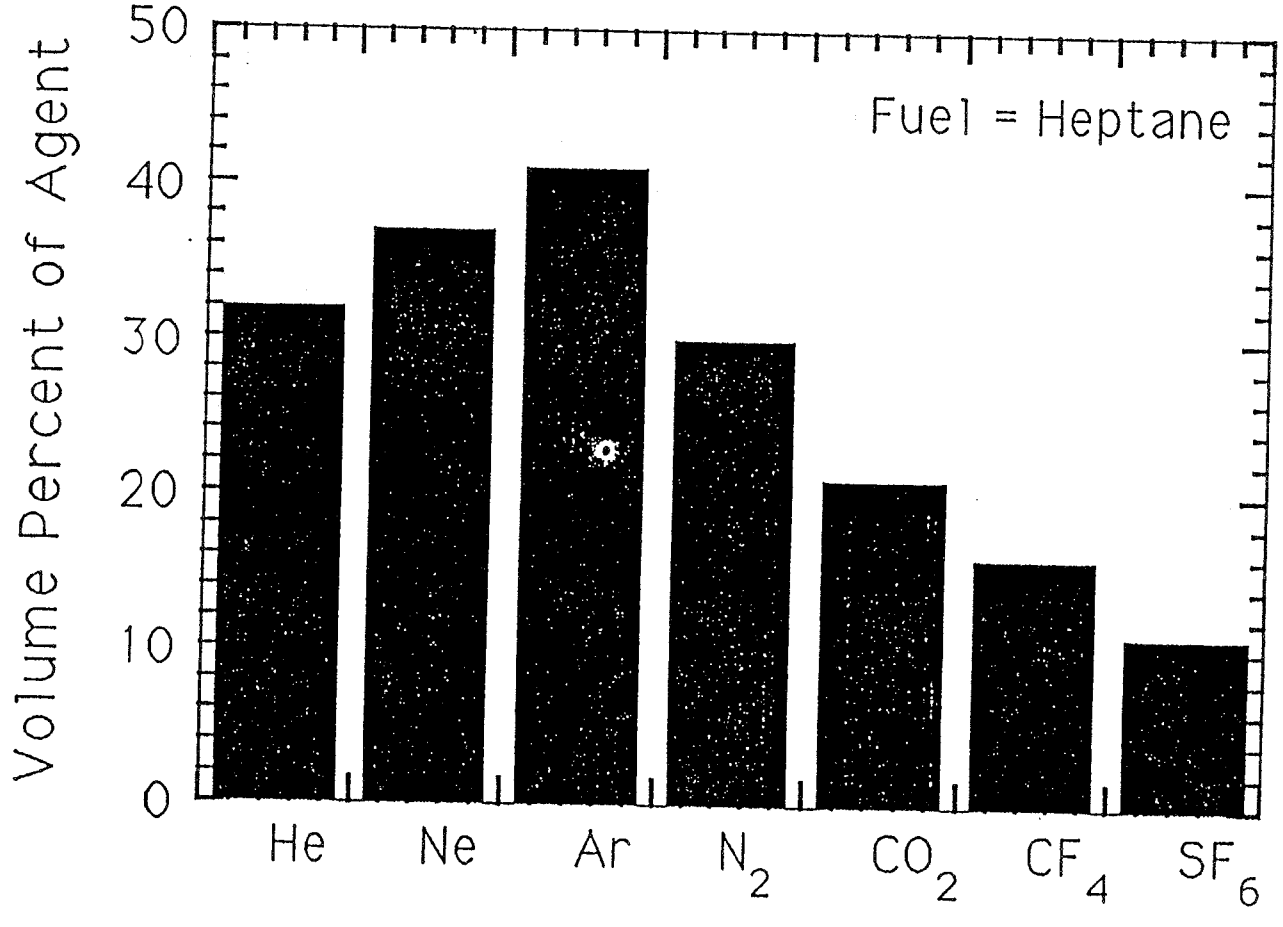

Agent = N_2
CONSTANT STRAIN RATE EXTINCTION RESULTS
FUEL = METHANOL
OXYGEN MASS FRACTION
0.145
0.140
0.135
0.130
0.125
250
300
350
400
450
500
OXIDIZER TEMPERATURE (K)
extinguished
Excess N_2
30%
35%


FUEL HEIGHT ADJUSTMENT DEVICE
FUEL RESERVOIR
48 cm
PYREX CHIMNEY
FUEL CUP
(28 mm OD)
GLASS BEADS
METERED AIR &
AGENT FLOW

CUP BURNER

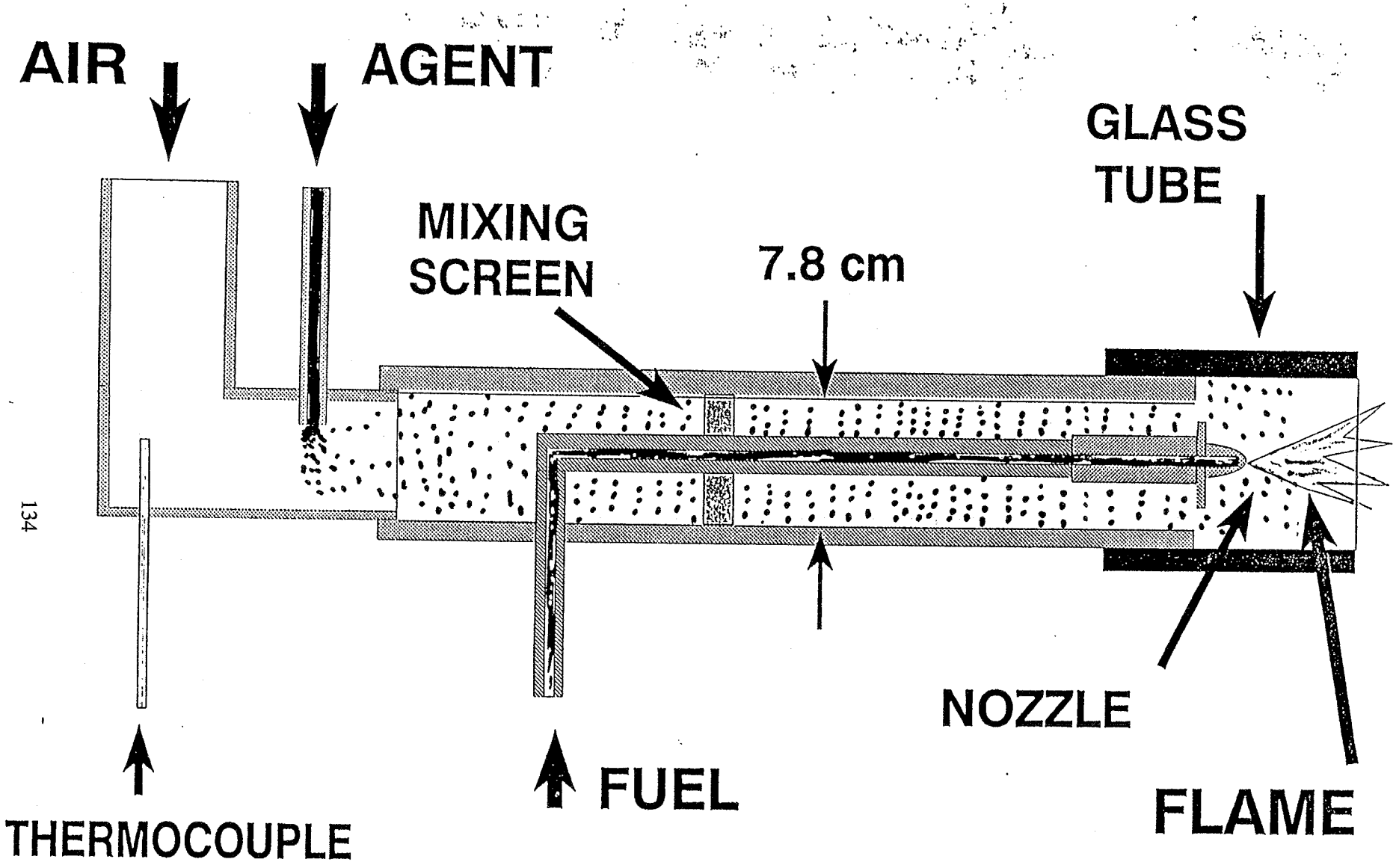

Cup Burner Extinction Results
Volume Percent of Agent in Oxidizer
Propane
Heptane
JP5
JP8
5606
83282
0
5
10
15
20
25
30
35
1301
FC-31-10
FC-218
HFC-227
HFC-236
FC-318
HCFC-124
FC-116
HFC-125
HFC-134a
HCFC-22
HFC-32/125
N2

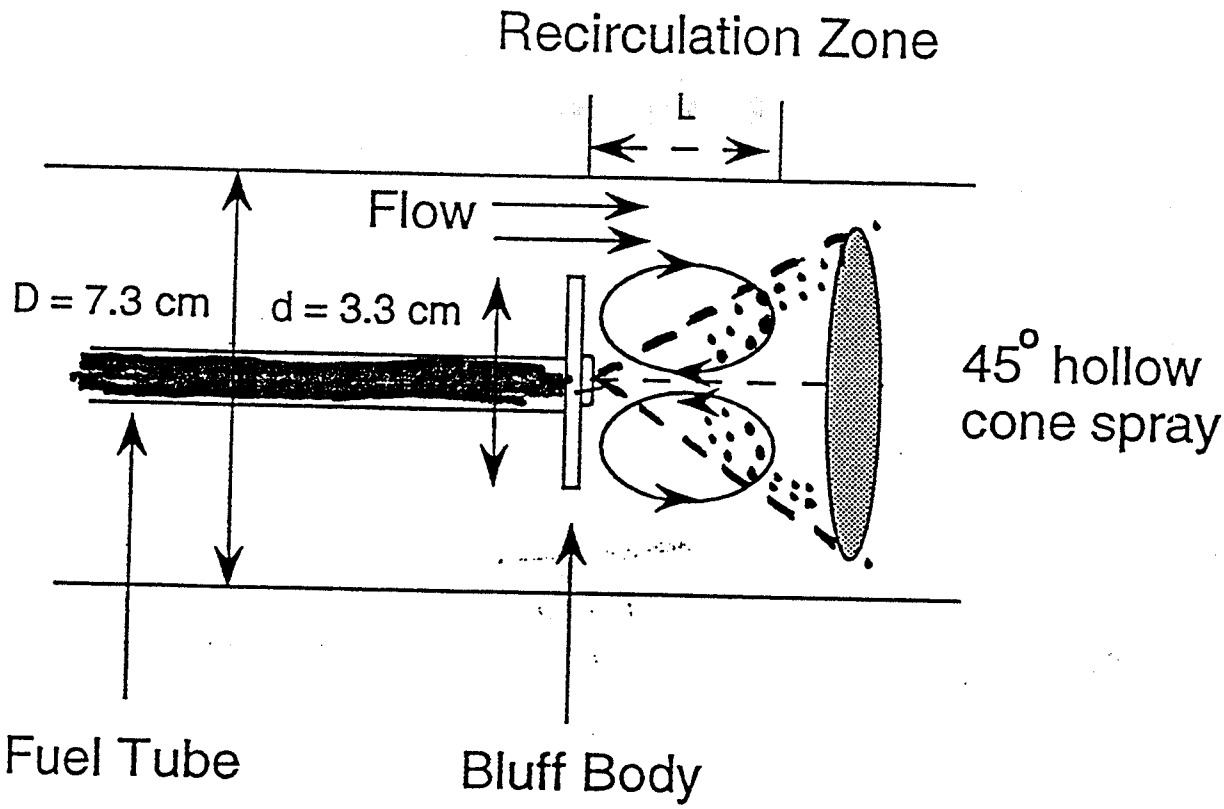
2. FLAME STABILIZATION BEHIND AN OBSTACLE

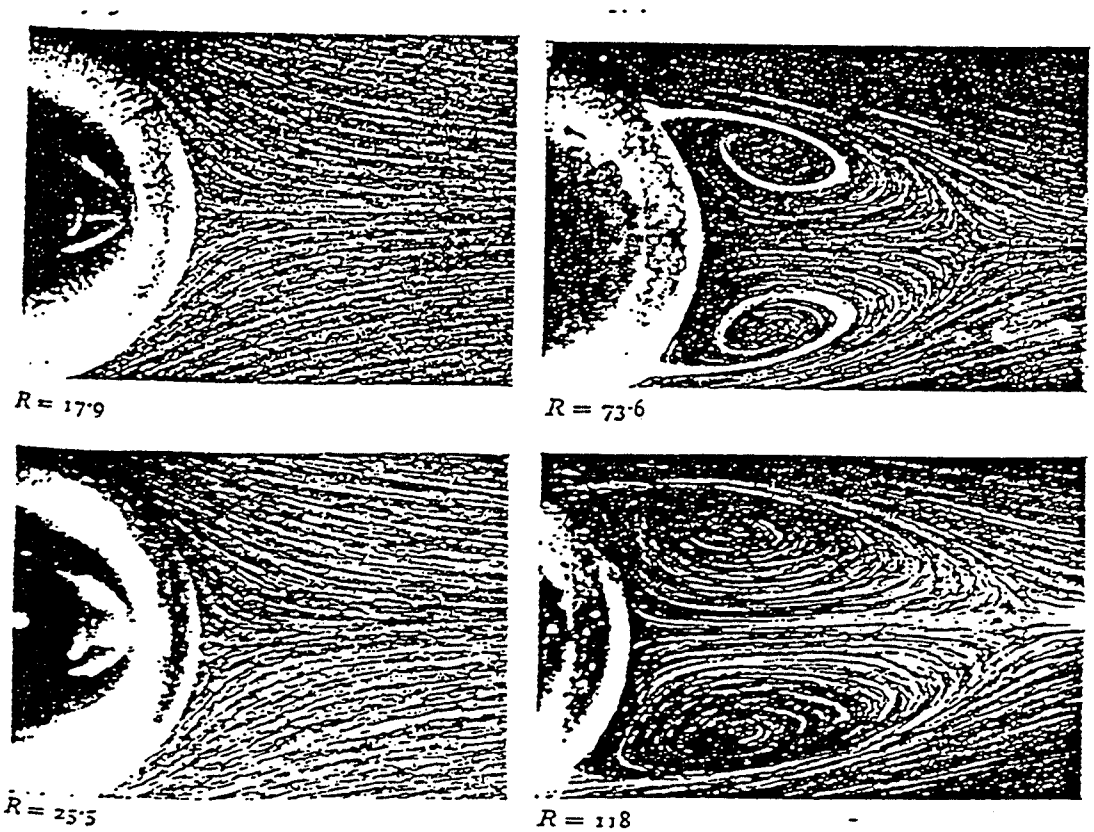


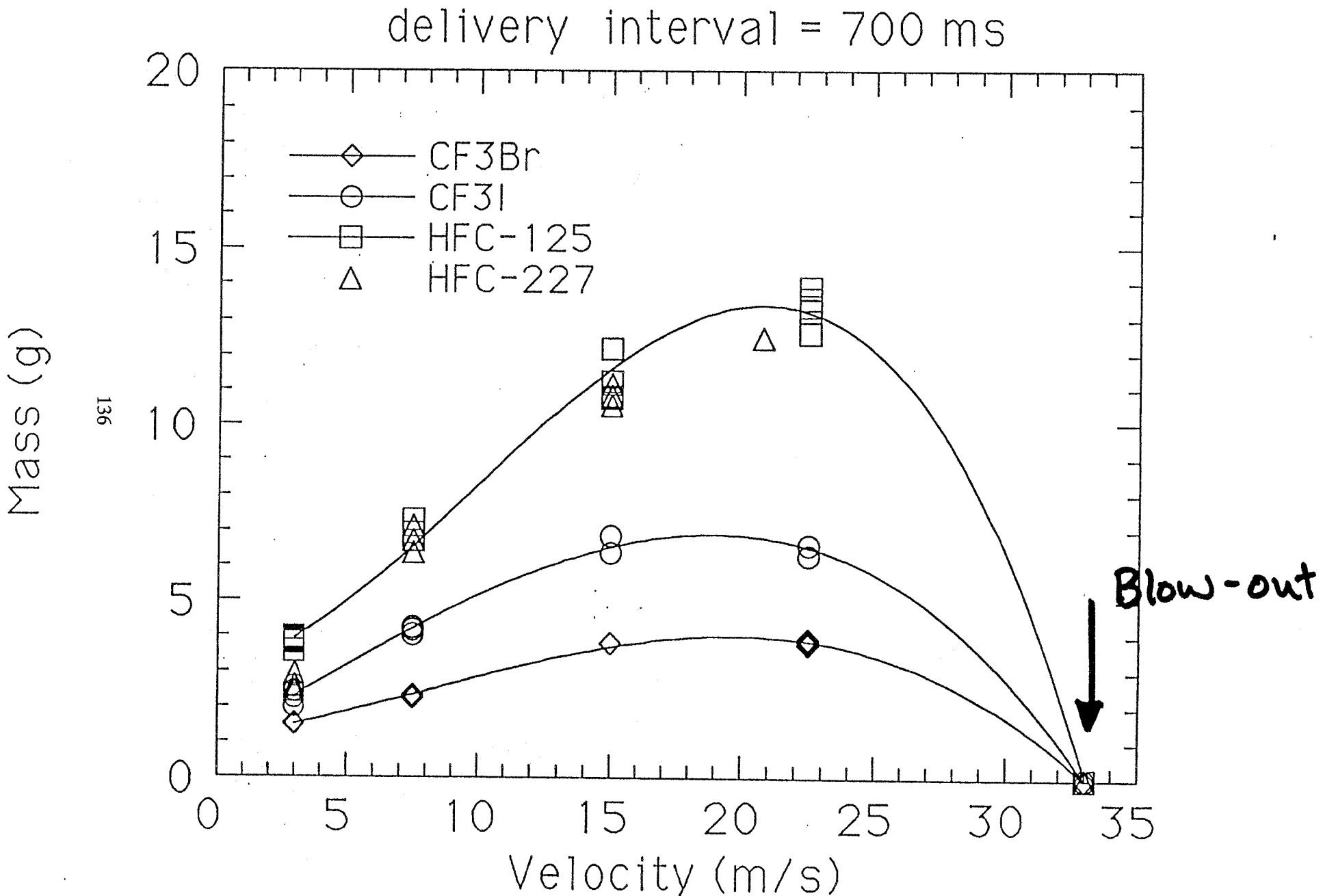
Flame Stability in a Recirculation Zone

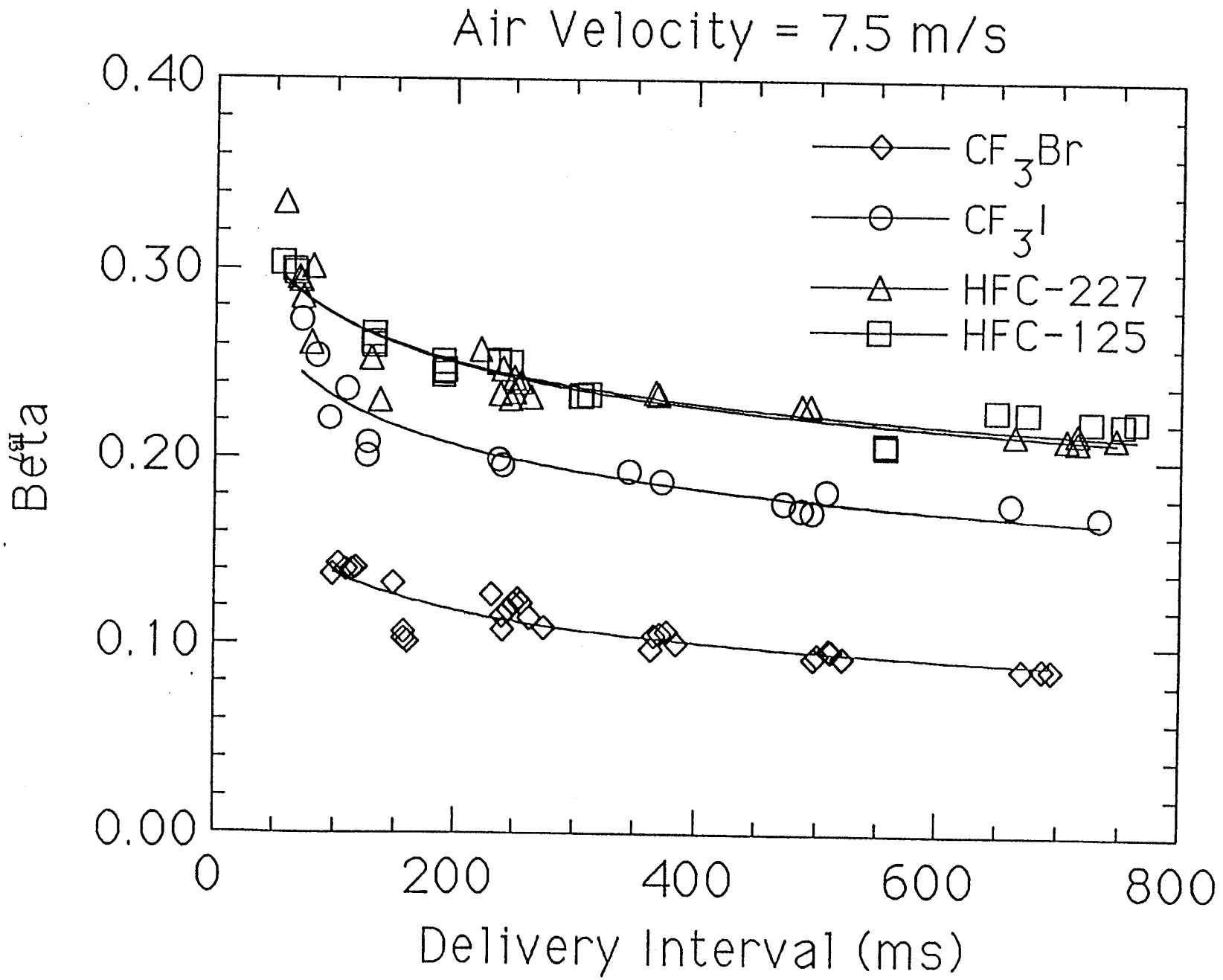
Parameter	increased Stability
velocity	decreased
temperature	increased
pressure	increased
turbulence	decreased
equivalence ratio	flammability peak
flame-holder size	increased
flame-holder drag coefficent	increased
geometric blockage	increased
fuel volatility	increased
atomization	finer


AIR
AGENT
GLASS
TUBE
MIXING
SCREEN
7.8 cm
NOZZLE
THERMOCOUPLE
FUEL
FLAME


Recirculation Zone
L
Flow
D = 7.3 cm
d = 3.3 cm
45° hollow
cone spray
Fuel Tube
Bluff Body


R = 17·9
R = 73·6
R = 25·5
R = 118


delivery interval = 700 ms
CF3Br
CF3I
HFC-125
HFC-227
Mass (g)
Velocity (m/s)
0
5
10
15
20
25
30
35
Blow-out


Air Velocity = 7.5 m/s
0.40
0.30
0.20
0.10
0.00
Beta
0
200
400
600
800
Delivery Interval (ms)
CF3Br
CF3I
HFC-227
HFC-125

AGENT ENTRAINMENT INTO RECIRCULATION ZONE

- Predict X_i as function of Δt, Velocity

Assumptions

- To extinguish flame, $X_i(\Delta t) \geq X_c$.
- Zone length (L) assumed constant.
- Instantaneous mixing occurs.
- Spray characteristics unimportant.

AGENT ENTRAINMENT INTO RECIRCULATION ZONE

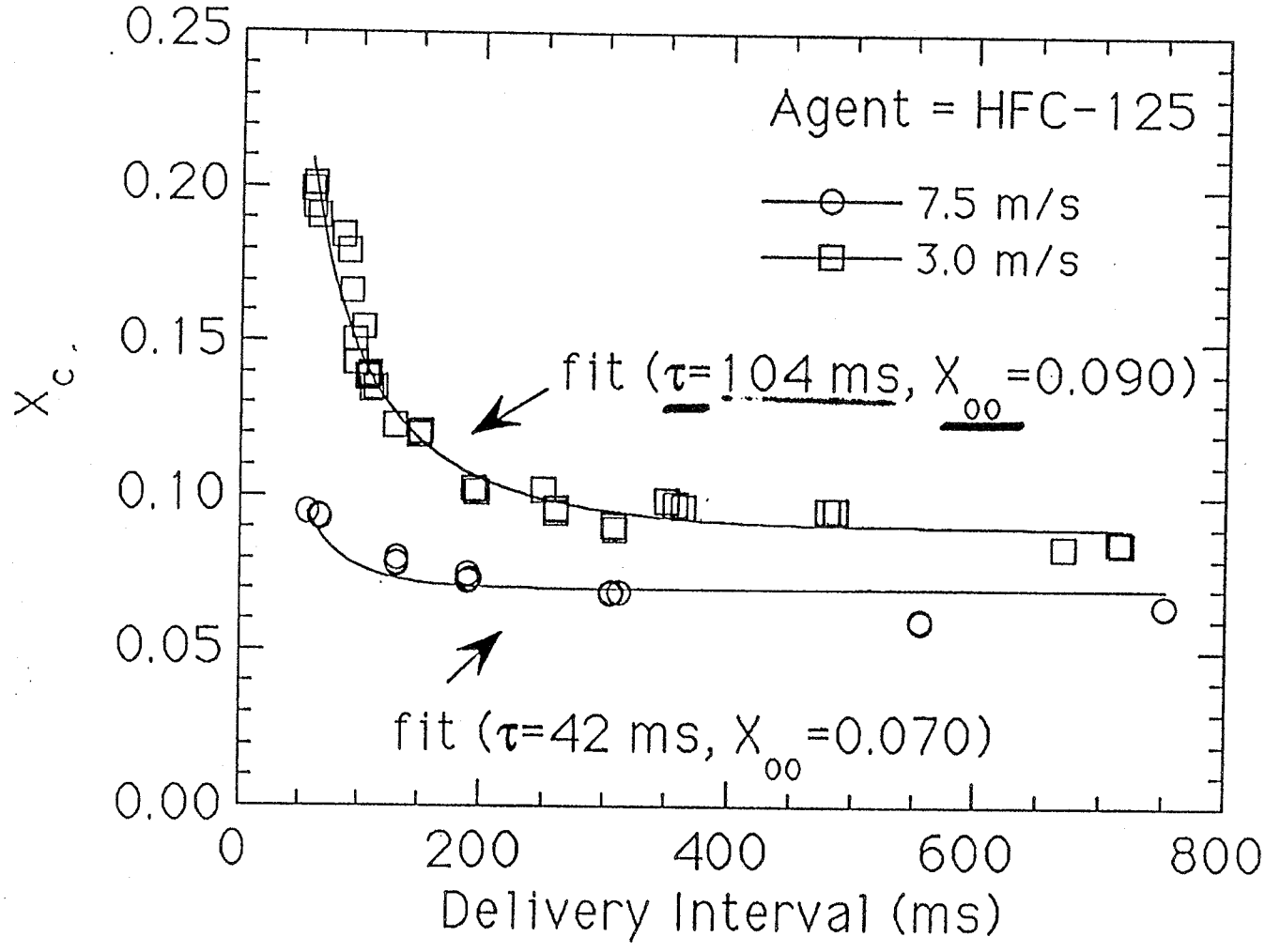
Results

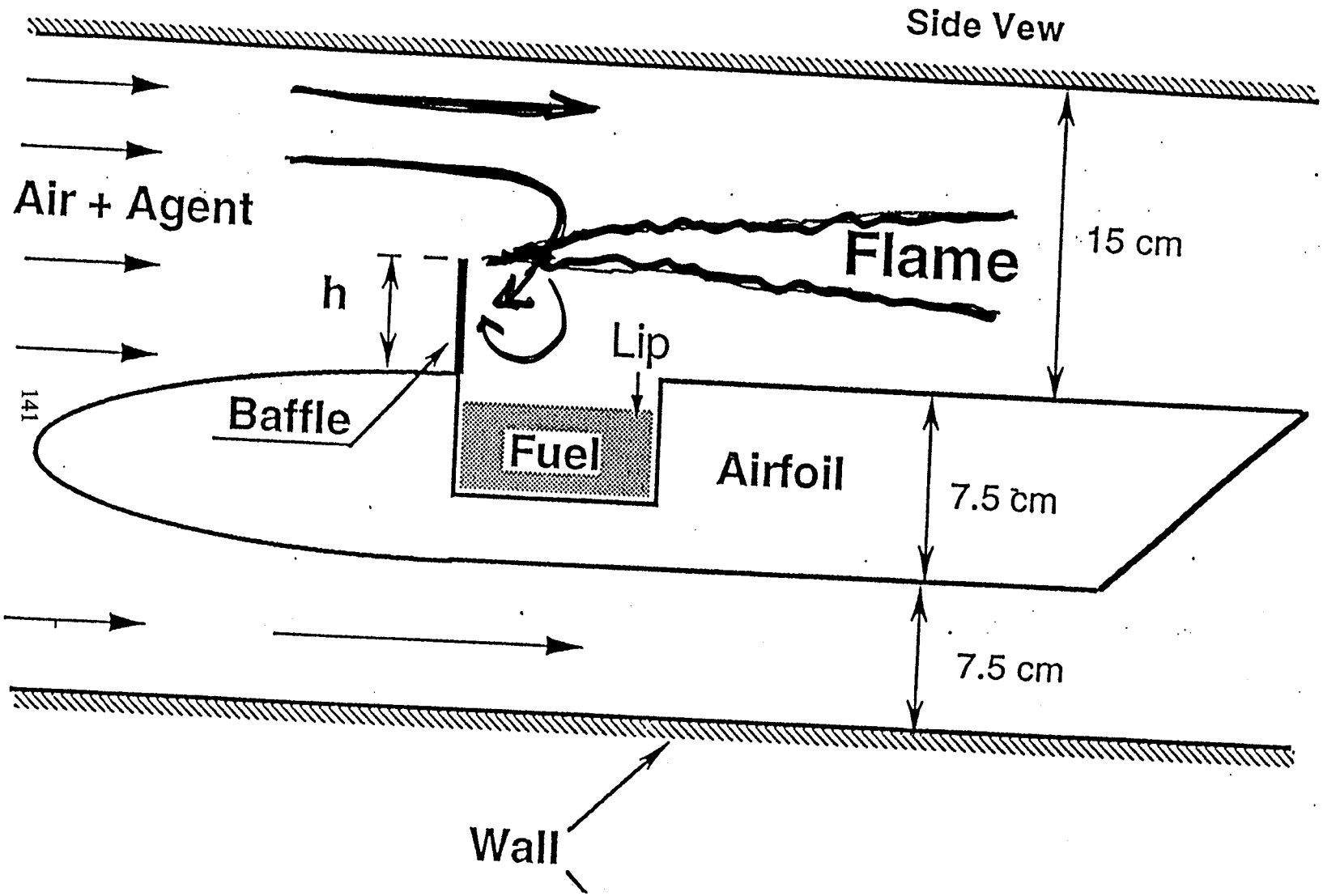
$$X_c(\underline{\Delta t}) = \frac{X_\infty(\underline{\Delta t} \gg \tau)}{1 - e^{(-\underline{\Delta t}/\tau)}}$$

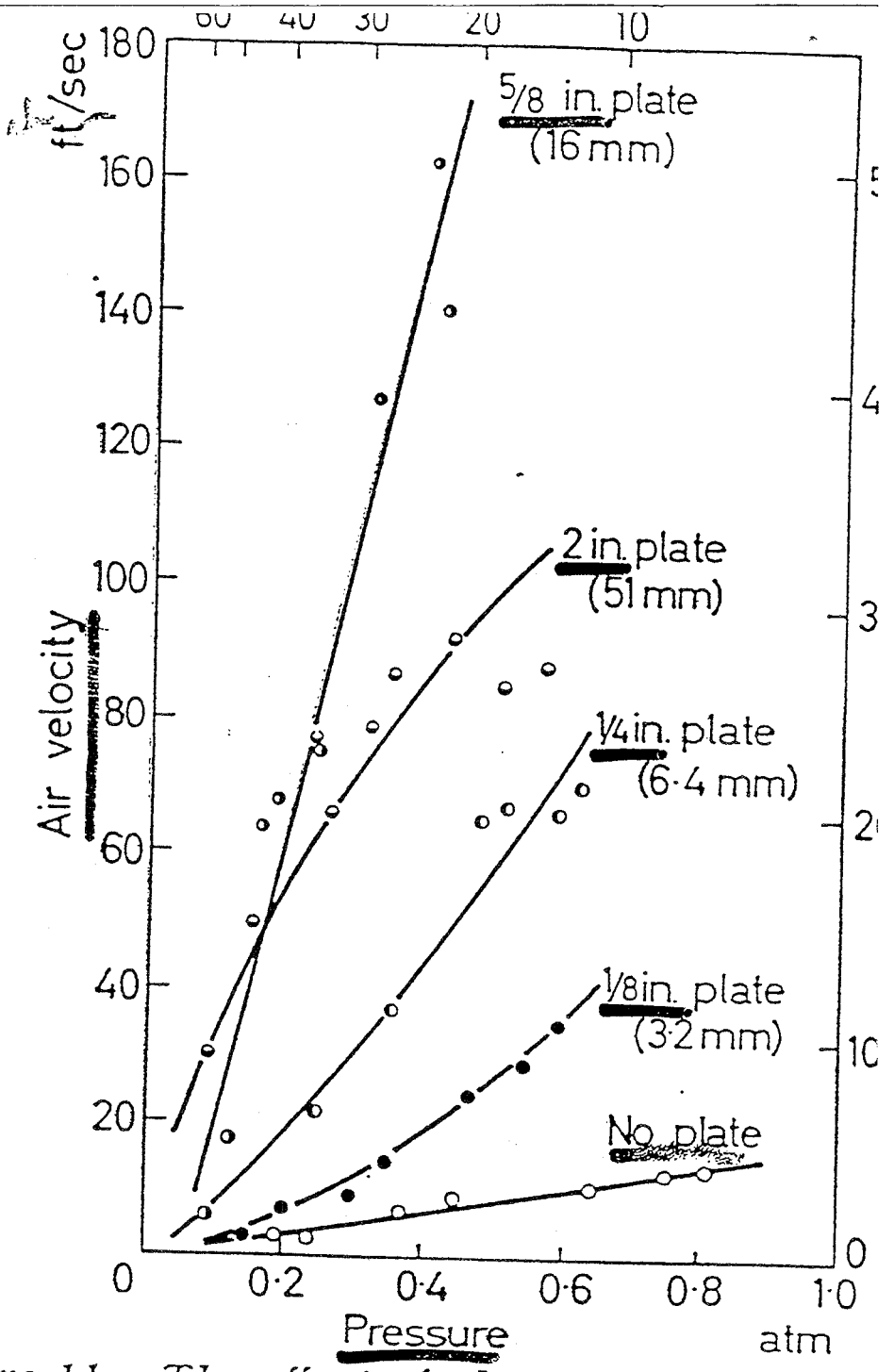
- $\underline{\Delta t}$ = injection interval.
- $\tau \approx L / V_{air}$
- $\underline{\Delta t_c} \geq -\tau \cdot \ln(1-X_\infty)$; i.e. $\Delta t_c \propto \tau$

Limitations

- X_∞ is not predicted, but is a function of agent chemistry.

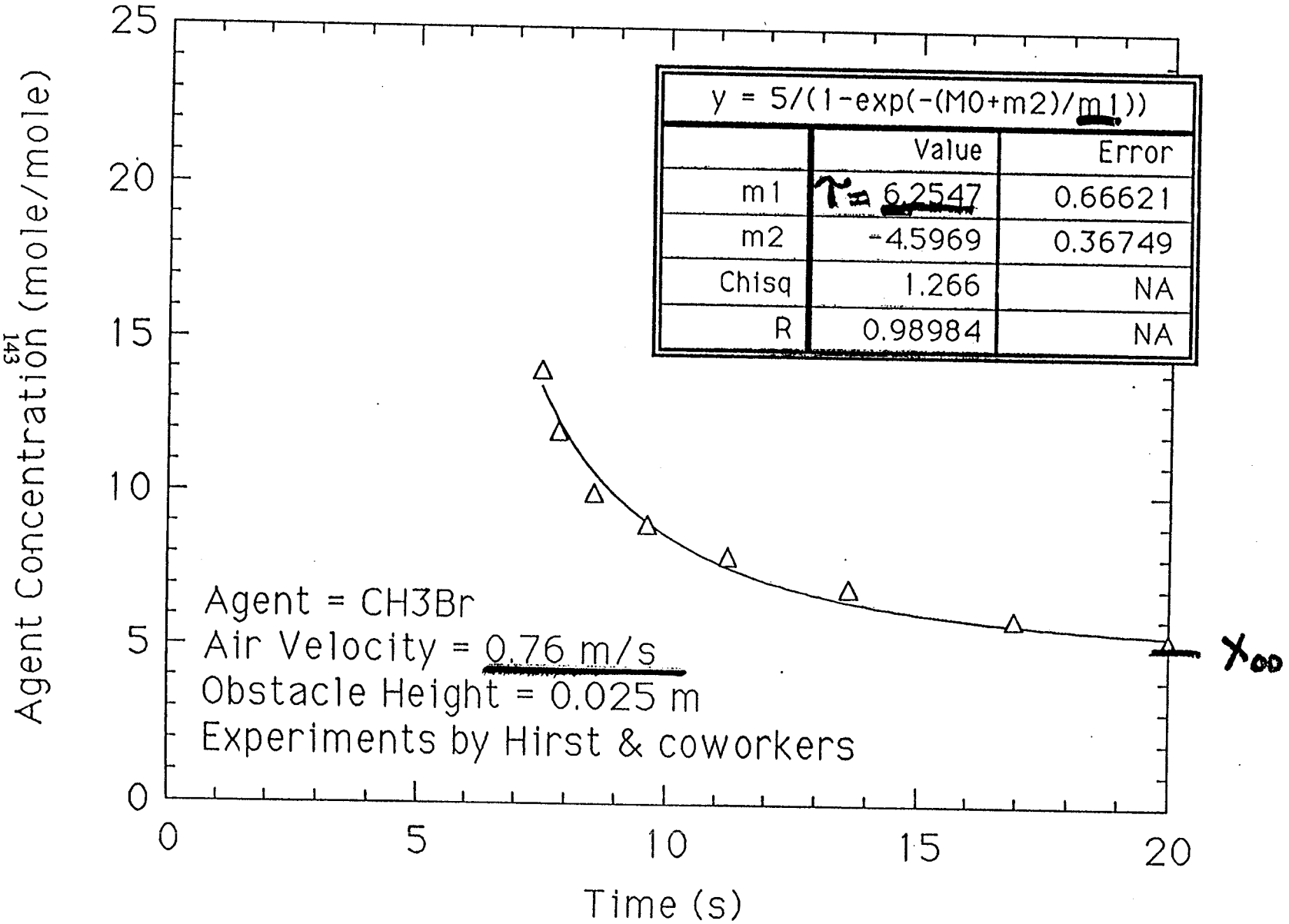

0.25
0.20
0.15
0.10
0.05
0.00
X_c
Agent = HFC-125
7.5 m/s
3.0 m/s
fit (τ=104 ms, X_{00}=0.090)
fit (τ=42 ms, X_{00}=0.070)
0
200
400
600
800
Delivery Interval (ms)

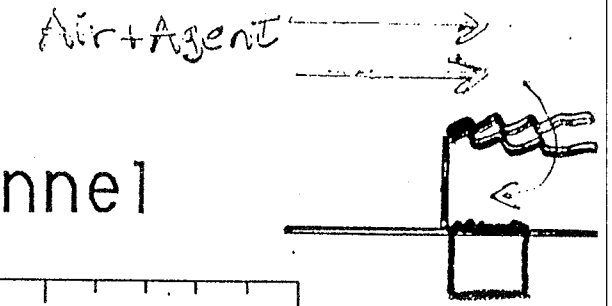

Side Vew
Air + Agent
h
Flame
15 cm
Lip
Baffle
Fuel
Airfoil
7.5 cm
7.5 cm
Wall



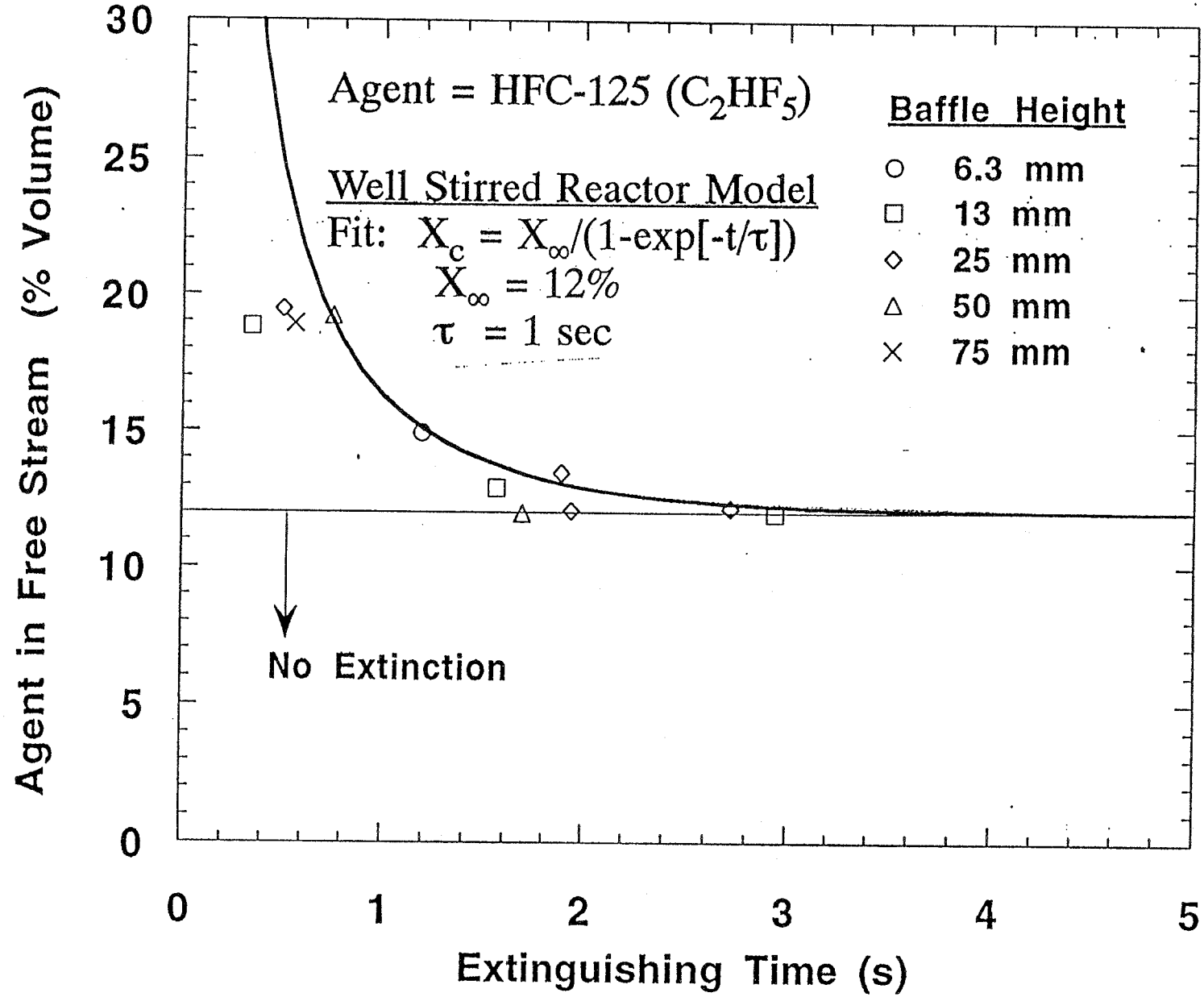
ure 11. The effect of plates at the front o tank (kerosine)

MIXING TIME DETERMINATION FOR POOL FIRE SUPPRESSION

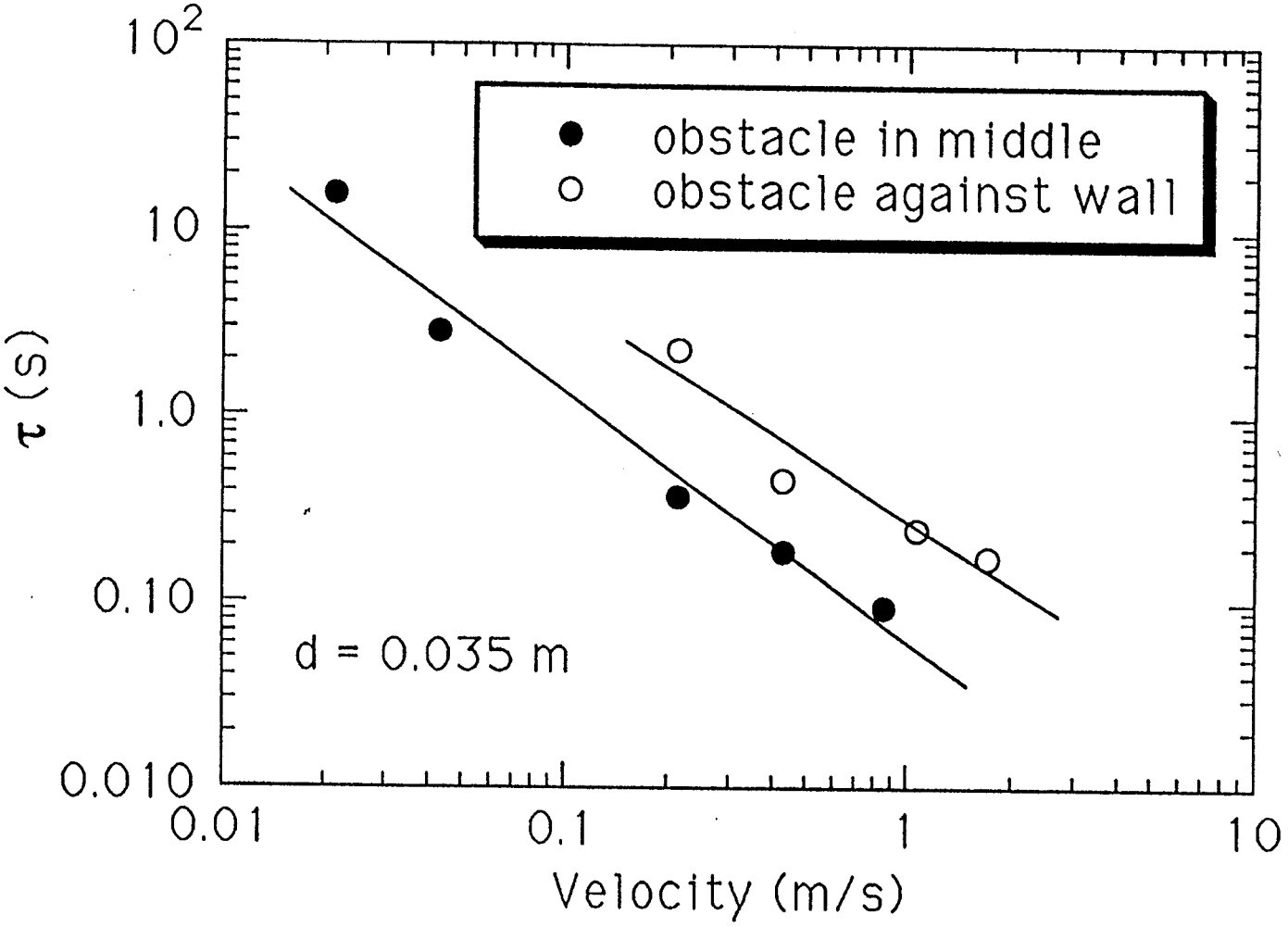




Pool Fires in Wind Tunnel



12 %


10^2
10
1.0
0.10
0.010
τ (s)
0.01
0.1
1
10
Velocity (m/s)
obstacle in middle
obstacle against wall
d = 0.035 m

CONCLUSIONS

- In general, baffle stabilized pool fires are <u>more dangerous</u> than baffle stabilized spray fires because:

  1. Long mixing times associated with agent entrainment into the recirculation zone of an obstacle against a wall.

  2. Higher agent concentration is required to achieve extinction.

  A fire of this sort may occur in an engine nacelle when a fuel puddle is located downstream of a rib.

- A fire with a heated oxidizer flow requires more suppressant to extinguish.