Joint Summer School on Fuel Cell and Hydrogen Technology
21-25 August 2011, Viterbo, Italy

Hydrogen fires tutorial

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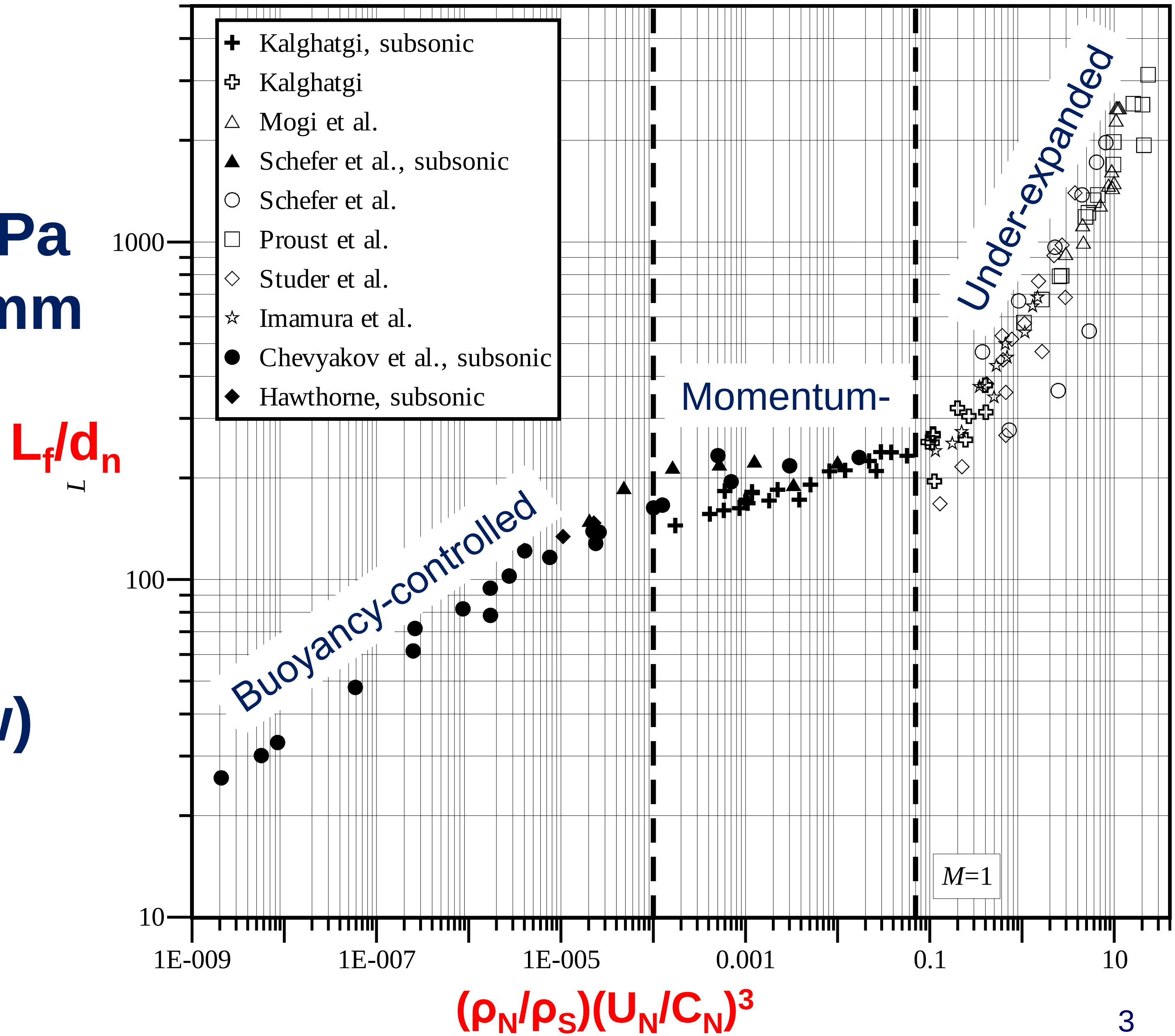
Purpose of this tutorial

- Assist with coursework!
- Give “ball park” figures for realistic examples
- Build on unignited jets covered yesterday – compare flammable envelope with flame length for the same scenario
- Focus on jet fires – specifically flame length

The dimensionless correlation

Validation:
***P* =0.1-90 MPa**
***d*=0.4-51.7 mm**

Line *M*=1
(choked flow)



The dimensionless correlation

- Y axis: L_f/d_n where L_f = flame length, d_n = nozzle diameter
- X axis: $(\rho_N/\rho_S)(U_N/C_N)^3$ where
- ρ_N = density at the nozzle exit,

  find the same way as with similarity law for unignited jets

  equal to 0.0838 kg/m^3 at normal temperature and pressure (NTP) for sub-sonic and expanded sonic jets

  IF the jet is underexpanded then the density is calculated by an **under-expanded jet theory** developed at the University of Ulster
- ρ_S =density of the surroundings = 1.205 kg/m^3 for air
- C_N = is the speed of sound in hydrogen at the nozzle exit,

$$C = \sqrt{\gamma \frac{P}{\rho}} = \sqrt{\gamma \frac{RT}{M}}$$

- U_N = the velocity of the hydrogen at the jet exit

  $U_N = C_N$ for sonic and supersonic jets,

  for subsonic jets:

$$U_N = \sqrt{2\frac{\Delta P}{\rho}}$$

Example: 200 bar, 1mm orifice

- Take storage temperature = 288 K
- ρ_N = 9.287 kg/m^3 (underexpanded jet theory- pressure ratio >1.9 bar)
- ρ_s = density of the surroundings, 1.205 kg/m^3 for air
- d_n = diameter = 0.001 (make sure in m, SI units)
- Yesterday we found the distance to the LFL

$$C_{ax}^{m} = 5.4\sqrt{\frac{\rho_N}{\rho_S}}\frac{D}{x} \qquad x = 5.4\sqrt{\frac{\rho_N}{\rho_S}}\frac{D}{C_{ax}^{m}}$$

x= 5.20 m

How does the flame length compare??

Y axis: L_f/d_n we know d_n, we need to find L_f

X axis: $(\rho_N/\rho_S)(U_N/C_N)^3$ ….. ρ_N = 9.287 kg/m^3 as above,

ρ_s = 1.205 kg/m^3 for air

jet is underexpanded so we don't need to calculate U_N and C_N

Therefore x axis = (9.287/1.205)*1 = 7.707

Example: 200 bar, 1mm orifice

x axis = 7.707

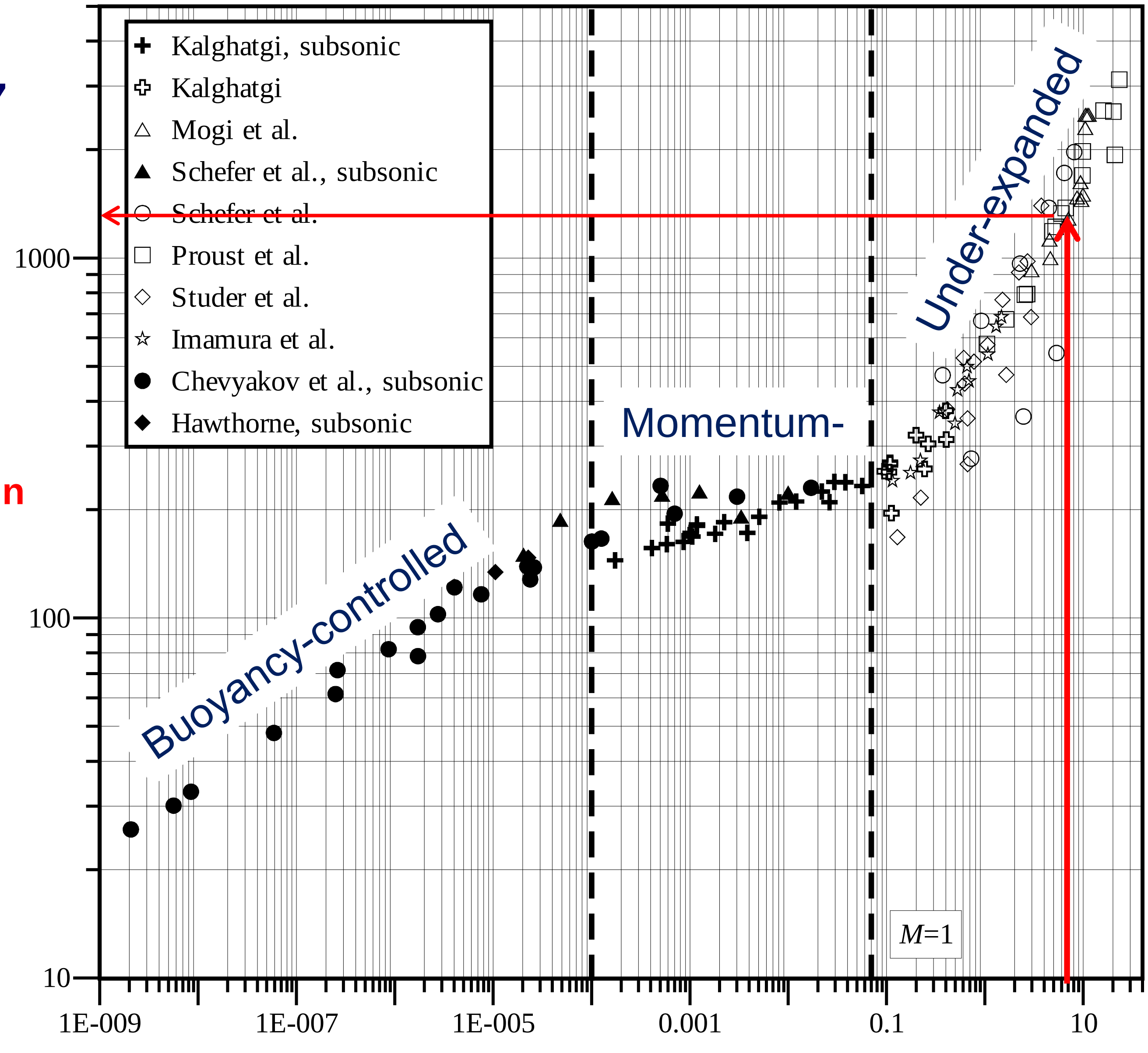
y axis ~ 1500

L_f/d_n ~ 1500

For 1mm
Flame length is in region of 1.5m

Remember distance to 4% was 5.2 m

What about a diameter of 5 mm??



Example: 200 bar, 1mm orifice, 3mm pipe

- Same case as previous, but now short length of 3mm diameter pipe after the 1mm orifice (i.e. like 1mm pipe restrictor)
- Note the jet is still underexpanded
- Assume no losses as jet expands and no drop in temperature
- Will the addition of a pipe affect the flame length???

How does the flame length compare??

Y axis: L_f/d_n we know d_n ,(now 3mm) we need to find L_f

X axis: $(\rho_N/\rho_S)(U_N/C_N)^3$ ….. ρ_s = 1.205 kg/m^3 for air

As before $U_N = C_N$

ρ_N= ?????

Mass flow rate is conserved in the pipe

Example: 200 bar, 1mm orifice, 3mm pipe

- Mass flow rate is conserved in the pipe
- Mass flow rate = ρ VA
- $\rho_{1mm} V_{1mm} A_{1mm} = \rho_{3mm} V_{3mm} A_{3mm}$
- Velocity is the speed of sound, the same in each case
- We know area because we know diameter $A=\pi d^2/4$
- $\rho_{3mm} = \rho_{1mm} A_{1mm}/A_{3mm}=9.287*(\pi(0.001)^2/4)/(\pi(0.003)^2/4)$
- ρ_{3mm} = 1.03 kg/m^3
- Therefore x axis = (1.03/1.205)*1 = 0.856

Example: 200 bar, 1mm orifice, 3mm pipe

x axis = 0.856

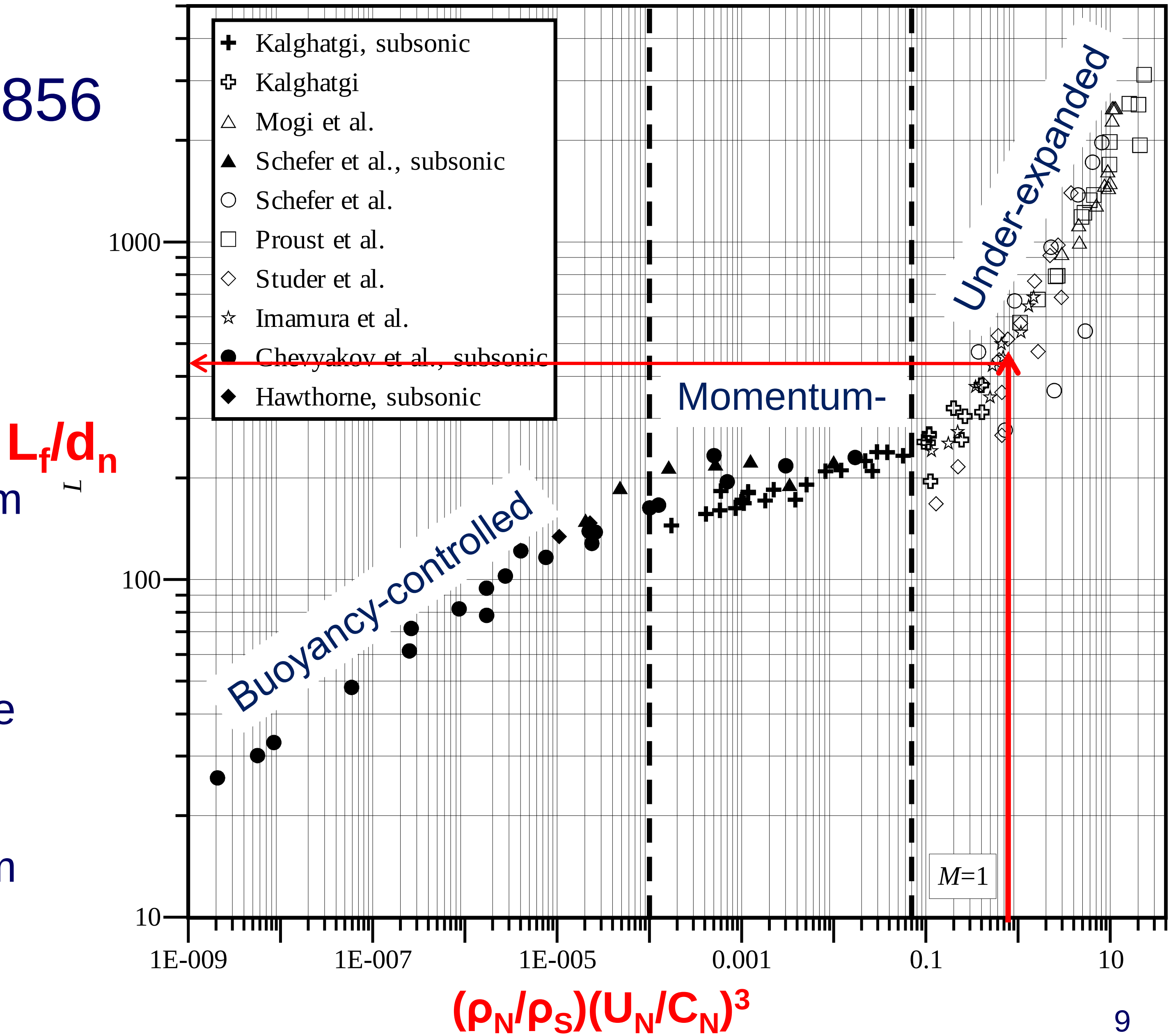
y axis ~ 420

L_f/d_n ~ 420

Remember for 1mm Diameter, no pipe
Lf = region of 1.5m

Now with 3mm pipe

Slightly reduced = 420*0.003 = 1.26 m



Example: 1.4 bar, 1mm orifice

- Take storage temperature = 288 K
- ρ_N = 0.0838 kg/m^3 (pressure ratio <1.9 bar)
- ρ_s = density of the surroundings, 1.205 kg/m^3 for air
- d_n = diameter = 0.001 m

Y axis: L_f/d_n we know d_n, we need to find L_f

X axis: $(\rho_N/\rho_S)(U_N/C_N)^3$ ….. ρ_N = 0.0838 kg/m^3 as above,

ρ_s = 1.205 kg/m^3 for air

We need to calculate U_N and C_N

$$C_N = \sqrt{\gamma \frac{RT}{M}} = \sqrt{1.4 \frac{288 * 8314}{2}} = 1295 m/s \qquad U_N = \sqrt{2 \frac{\Delta P}{\rho}} = \sqrt{2 \frac{40000}{0.0838}} = 977 m/s$$

X axis = (0.0838/1.205)(977/1295)^3=0.03

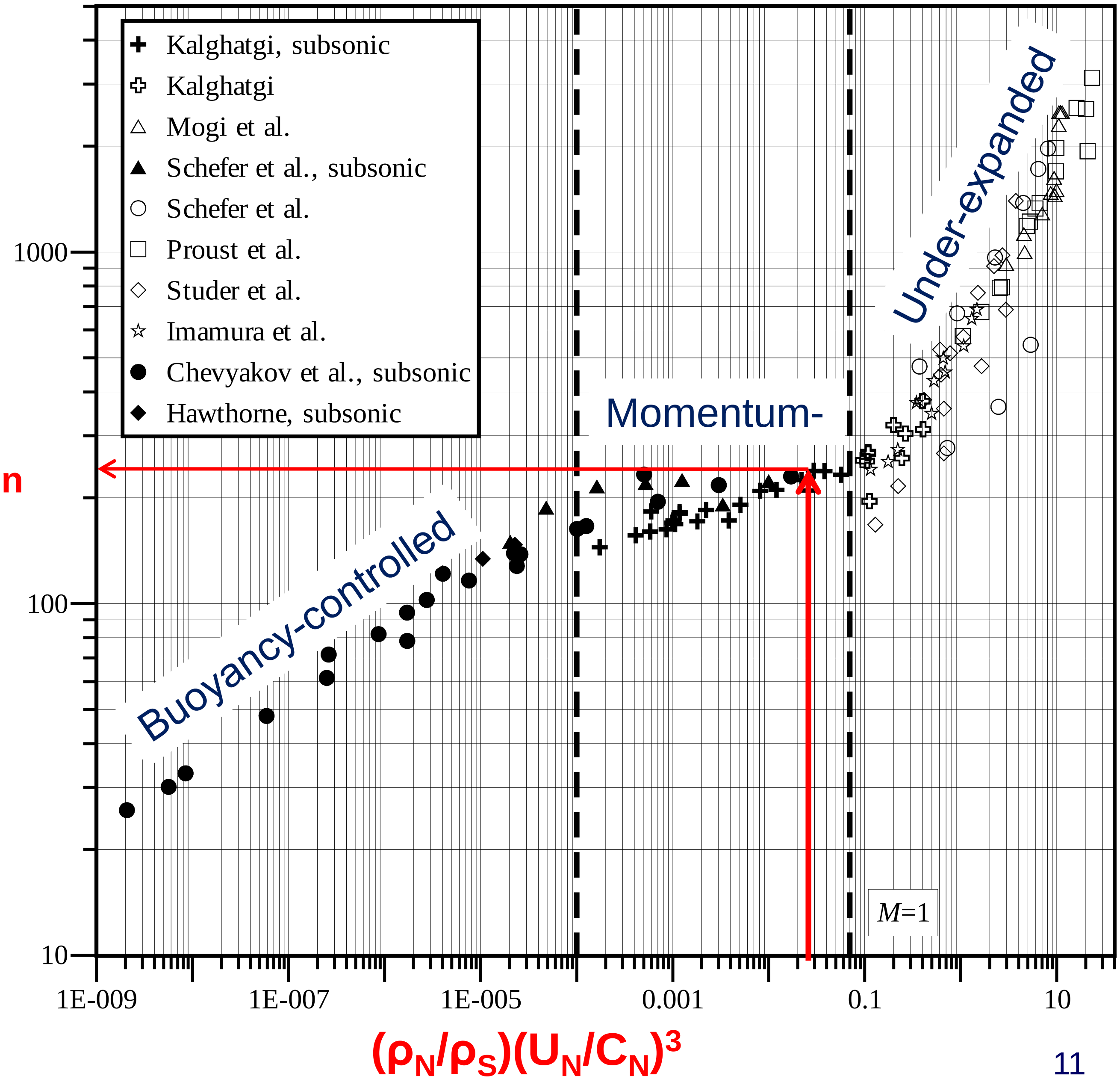
Example: 1.4 bar, 1mm orifice

x axis = 0.03

y axis ~ 250

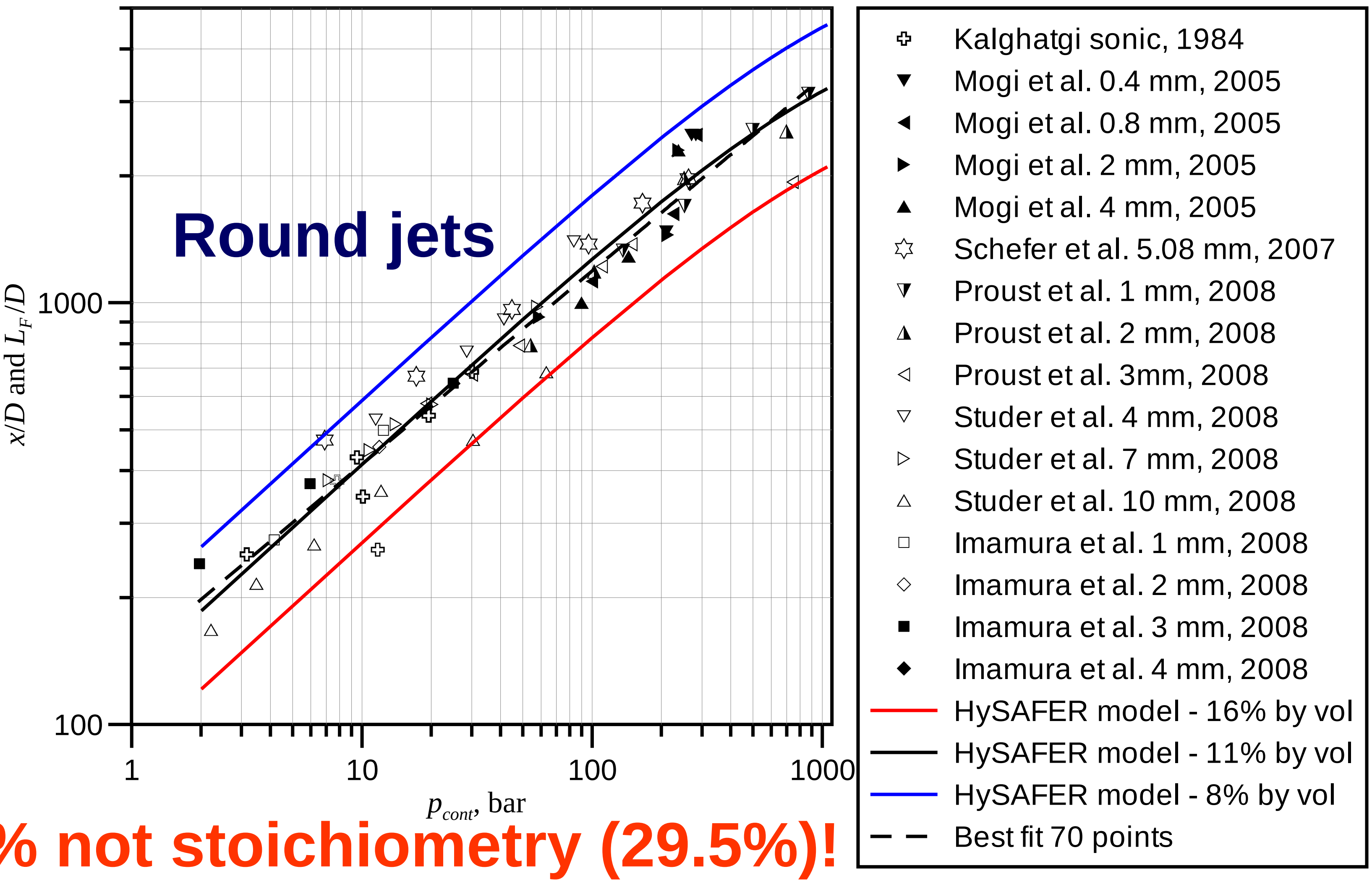
L_f/d_n ~ 250

Flame length = 0.25m



Separation distance – one language

- **Flammable envelope** – 4% by volume (LFL)
- **Jet flame tip location** – 11% in unignited jet (8-16%)



11% not stoichiometry (29.5%)!

Any questions?

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