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Flaring Biogas: Efficiency and Emissions

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Flaring Technologies

Flaring Technologies

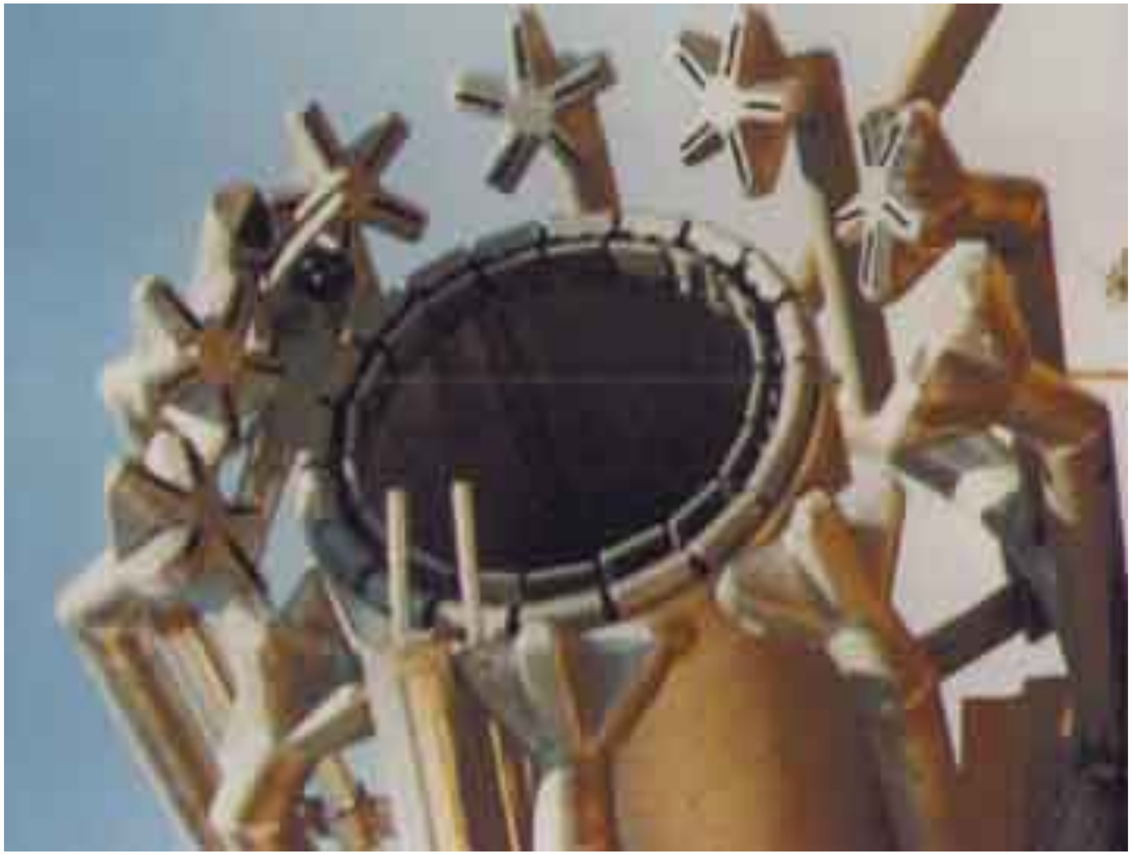
Elevated Flare

- simple
- low cost
- small footprint
- visible flame
- exposed to wind

Enclosed Flare

- more complicated
- higher cost - refractory, internals
- larger footprint
- no visible flame
- some protection from wind

Industrial flare tips



Steam Assist

Air Assist

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Biogas Sources

- Decomposition of organic material
  - from landfills
  - anaerobic digestion of livestock manure or other agricultural residues.
  - anaerobic digestion of sewage
  - anaerobic digestion of organic fraction of MSW

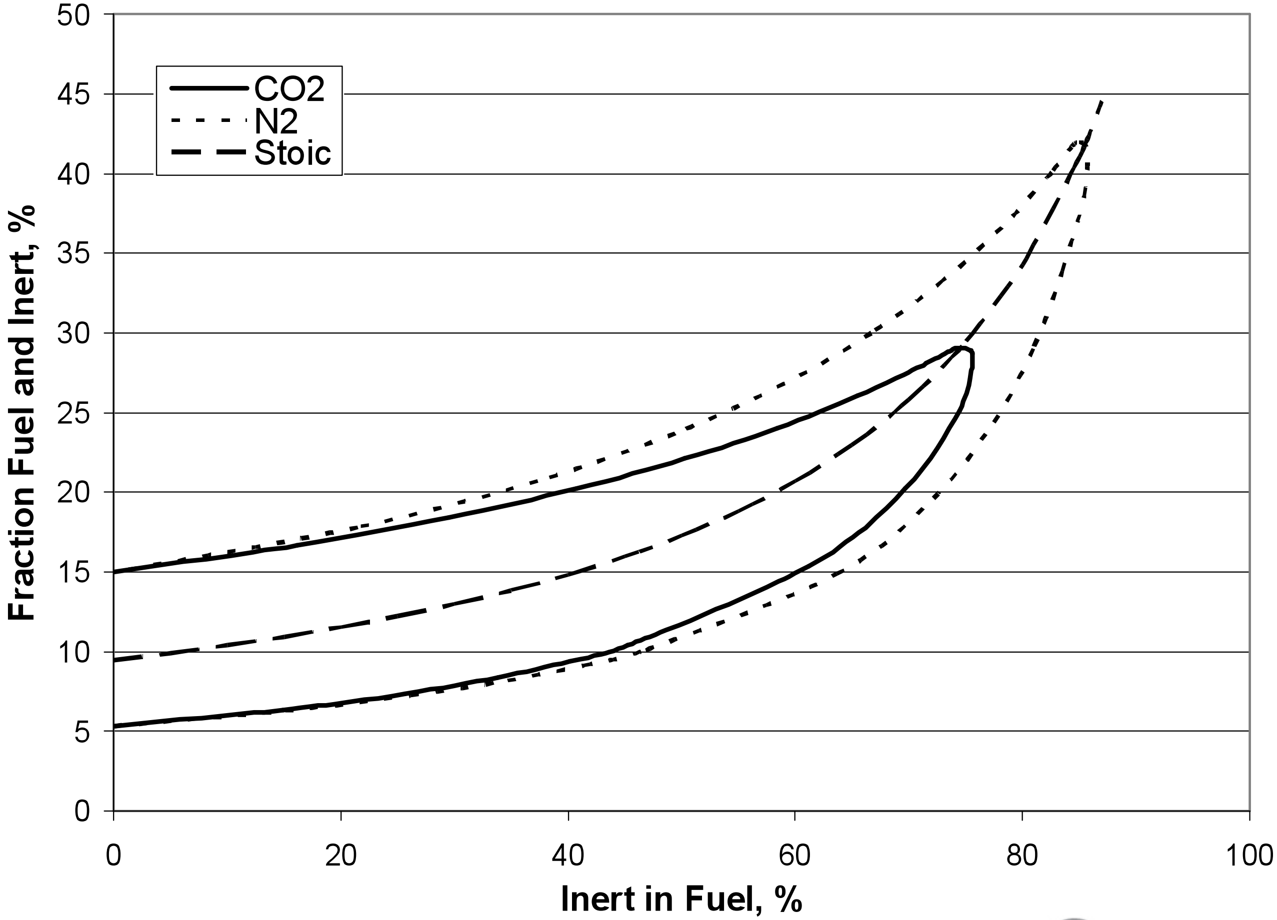
Biogas Composition

- Composition of Biogas
  - Primarily mixture of methane and CO_2
  - Methane from 40% to 80%.
  - Traces of other compounds
    - H_2S
    - NH_3
    - VOCs

Other Flare Gases

- Production Flares (Oil and Gas)
  - mostly methane, also some sour gas.
- Refineries and Chemical Plants
  - whatever is in the plant
  - nitrogen for flushing, dilution.
- Steel Mills
  - coke oven gas, blast furnace gas, BOF gas
  - hydrogen, carbon monoxide, carbon dioxide, nitrogen

Flammability of Methane with Dilution



Dilution changes the combustion properties of methane

Wind can push the flame into wake



Performance Measures

- Flare objective is to convert CH_4 to CO_2 and H_2O; actual products include CO and unconverted CH_4.
- Conversion Efficiency $$CE = \frac{\text{mass C out as } CO_2}{\text{mass C in as } CH_4}$$
- Prefer to report on Conversion Inefficiency, CI =100%-CE

Performance Measures

- Fuel Slip, FS, unconverted methane

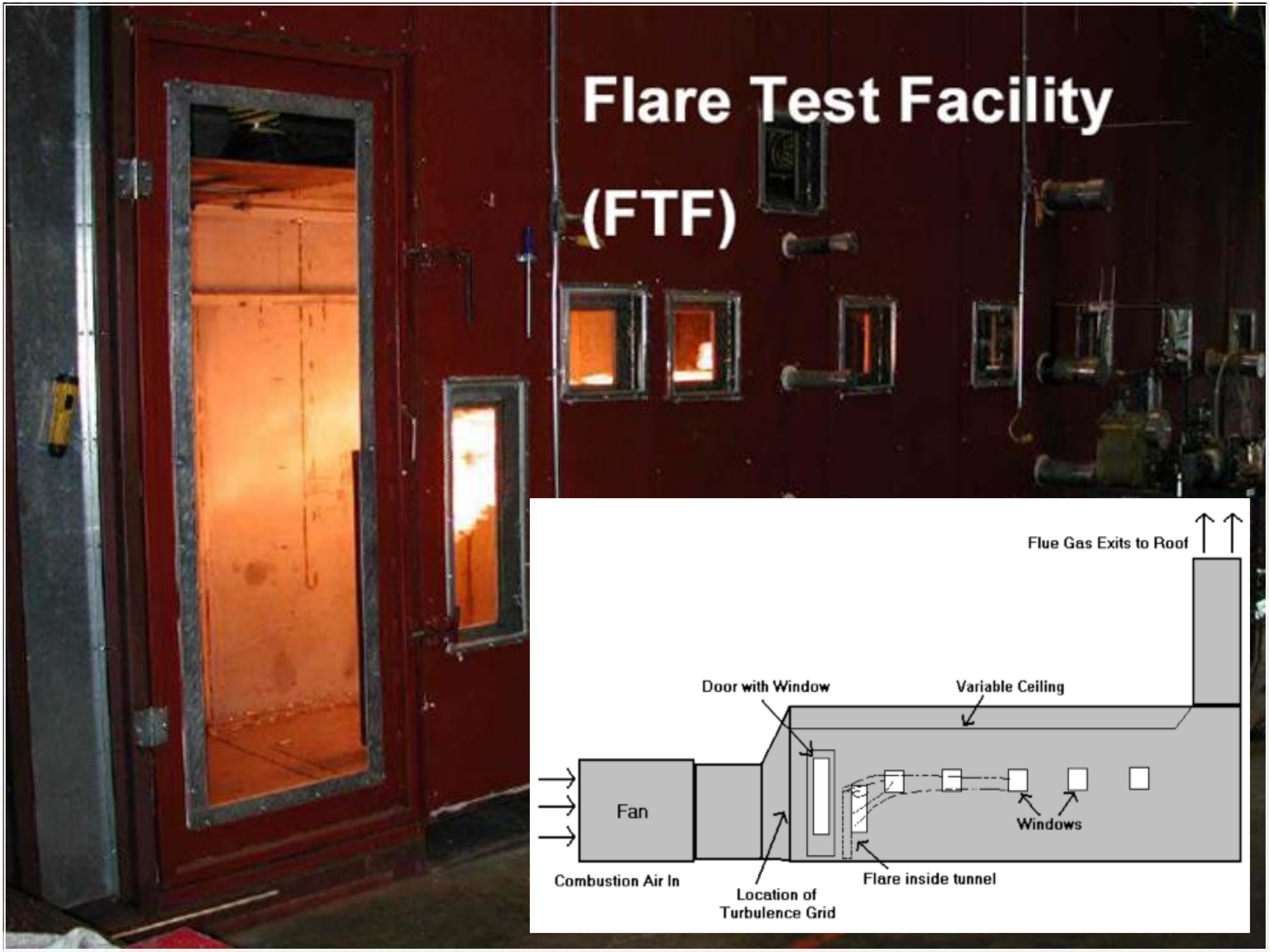
$$FS = \frac{\text{mass } CH_4 \text{ out}}{\text{mass } CH_4 \text{ in}}$$

- Commonly report Destruction Efficiency, DE = 100% - FS

- Regulations require 200 BTU/scf (20% methane) to guarantee 98% DE.

Performance Expectations

	Methane Destruction Technique	Destruction Efficiency	Notes
A	Open Flare: 40 CFR 60.18 Compliant	96%	96% can be used if the flare is operated according to 40 CFR 60.18, otherwise 50% should be used.
B	Open Flare: 40 VFR 60.18 Non-Compliant	50%	
C	Enclosed flare that achieves a minimum retention time of 0.3 seconds.	98%	Includes a burner and damper system for combustion control.
D	Enclosed Flares with retention time greater than 0.3 seconds.	90%	98% can be used if the enclosed flare otherwise 90% should be used.


Flare Test Facility
(FTF)
Flue Gas Exits to Roof
Door with Window
Variable Ceiling
Fan
Windows
Combustion Air In
Location of
Turbulence Grid
Flare inside tunnel

FTF Description

- Single pass wind tunnel
- Total flow sampled in stack
  - O_2, CO, CO_2, CH_4, NMHC
- Fuels: NG, Propane, liquids, inerts
- X-wind speed: 5 to 45 km/h
- Flare pipe sizes: 1” to 6” dia.
- Various appurtenances, steam injection.

Other Work on Dilution

- EPA studies (Pohl et al., 1984-86)
  - Stability limits with N_2 dilution and jet speed
- Noble et al. (1984)
  - Stability correlated with (Q/LHV)(UFL/LFL)
- Walsh et al. (2002)
  - Stability envelope for H_2 / N_2 flare gas.
- Johnson and Kostiuk (1999)
  - Methane diluted with CO_2, in low momentum regime.

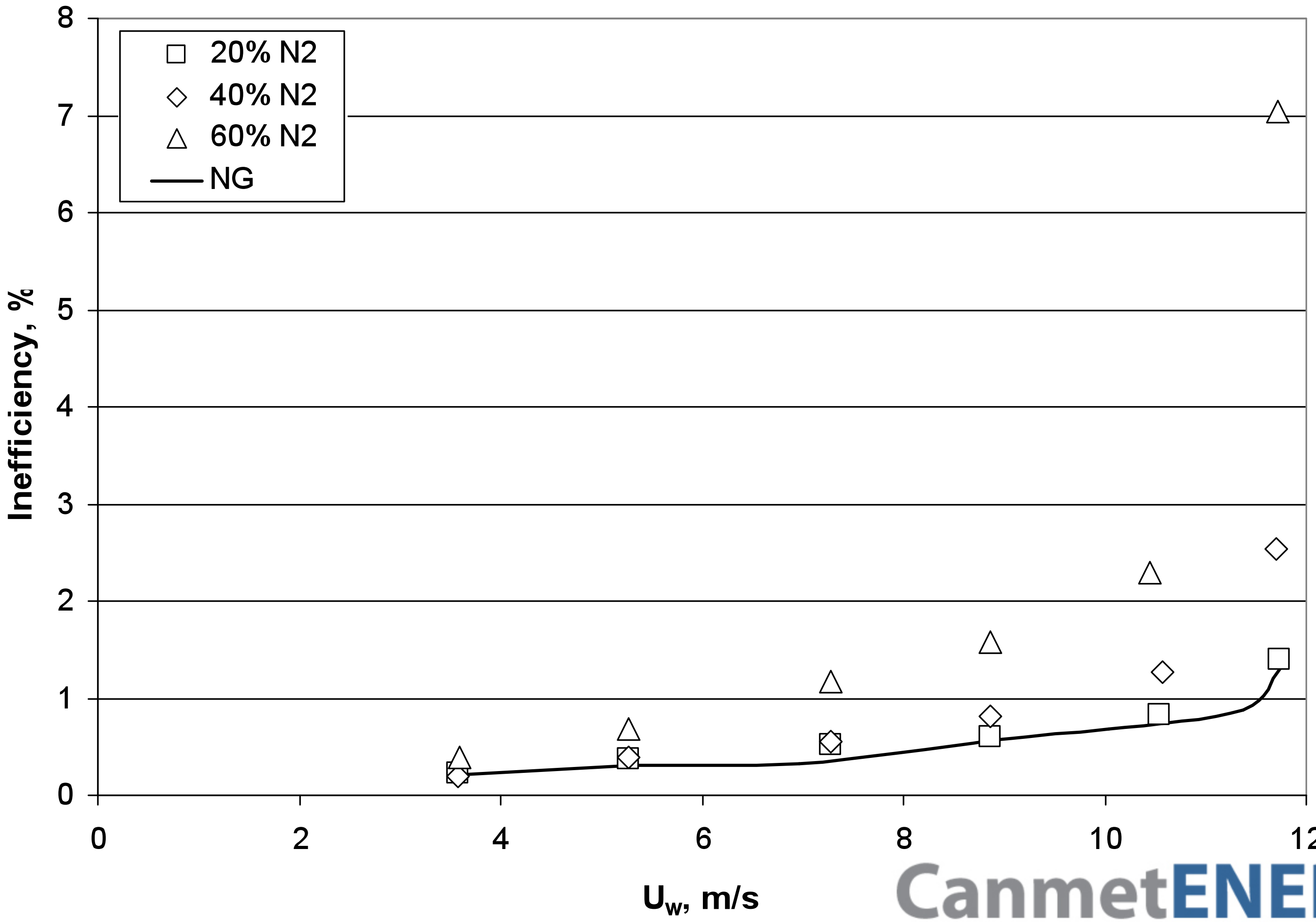
FTF Tests

- Flare pipe: 4” Sch. 40, 40” long.
- Fuel: mixtures of natural gas (NG) with nitrogen or carbon dioxide.
- Fuel rate: 21 kg/h total.
- Wind speed from 3.6 m/s to 11.5 m/s (13 km/h to 42 km/h)

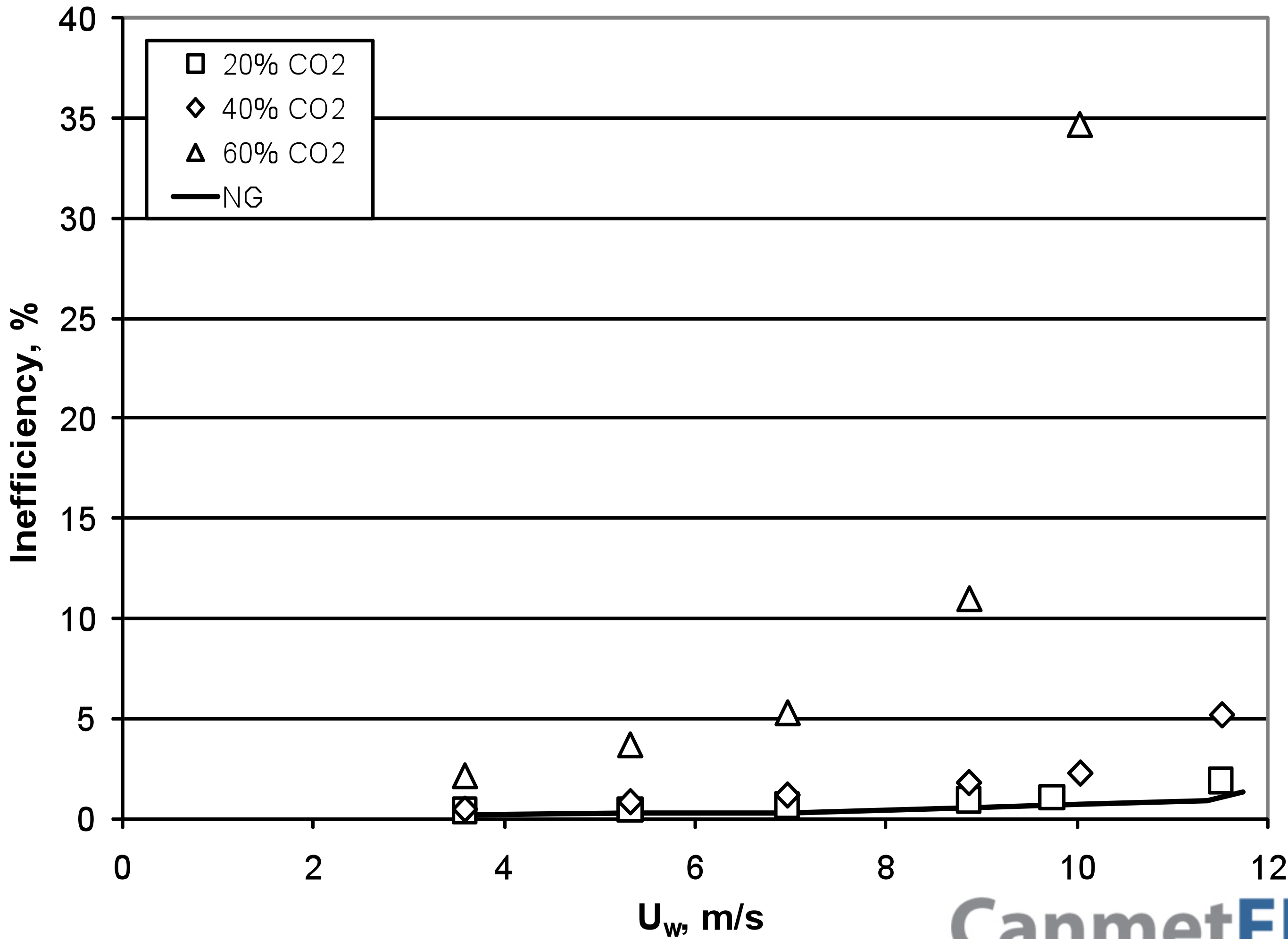
Dilution Test Conditions

Mixture	Fraction Inert		Energy Content	LFL	UFL	UFL/ LFL	Pipe Exit Velocity
	% mass	% volume	MJ/m^3	%	%		m/s
NG/CO_2	38	19	29.8	6.7	16.8	2.5	0.74
	57	35	24.3	8.6	19.2	2.2	0.63
	76	55	16.3	13.2	23.6	1.8	0.52
NG/N_2	30	21	29.2	6.8	18.1	2.6	0.86
	50	39	22.5	8.7	20.8	2.4	0.78
	70	60	14.5	13.5	27.0	2.0	0.74

Effect of N_2 Dilution



Effect of CO_2 Dilution



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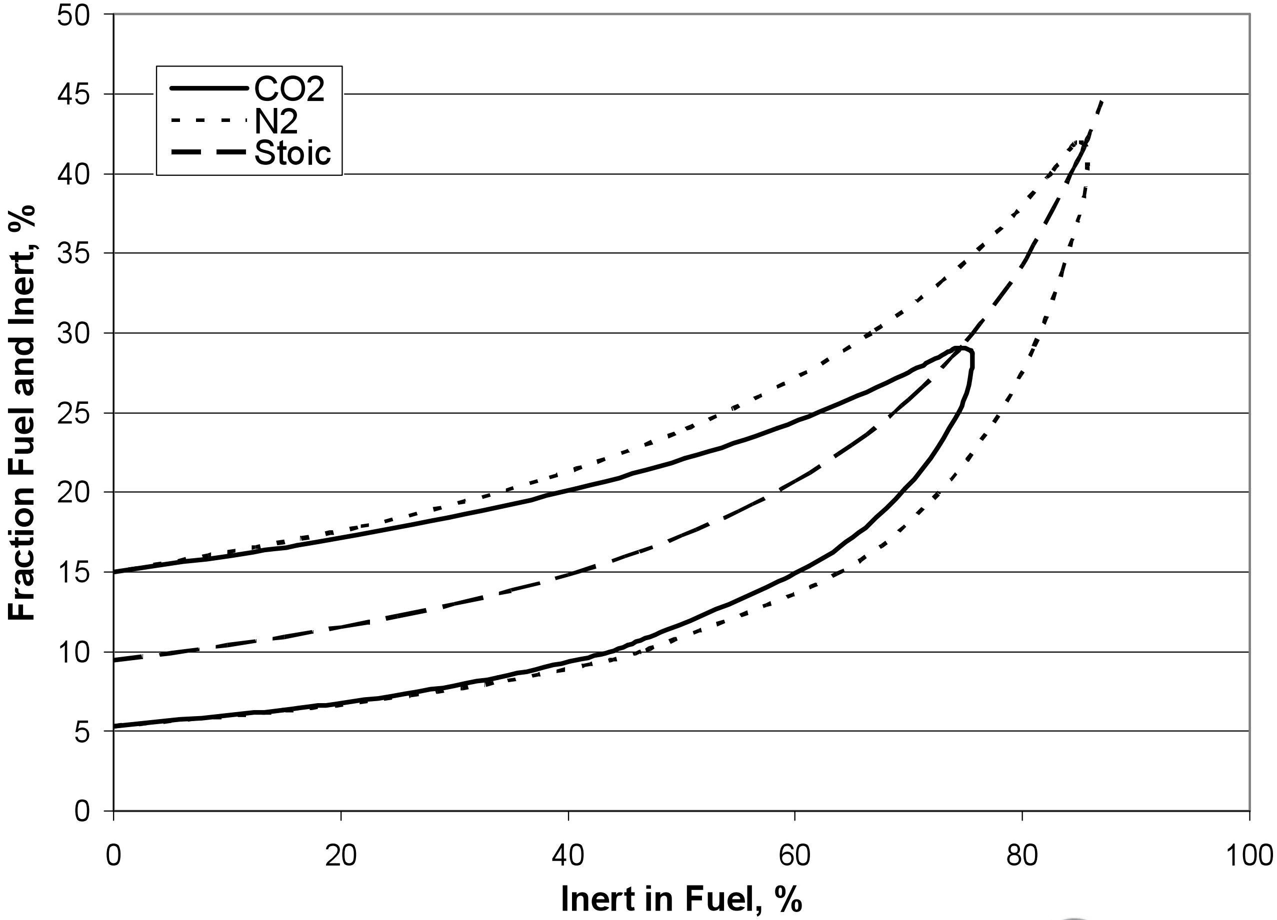
Flammability of Methane with Dilution



Dilution changes the combustion properties of methane

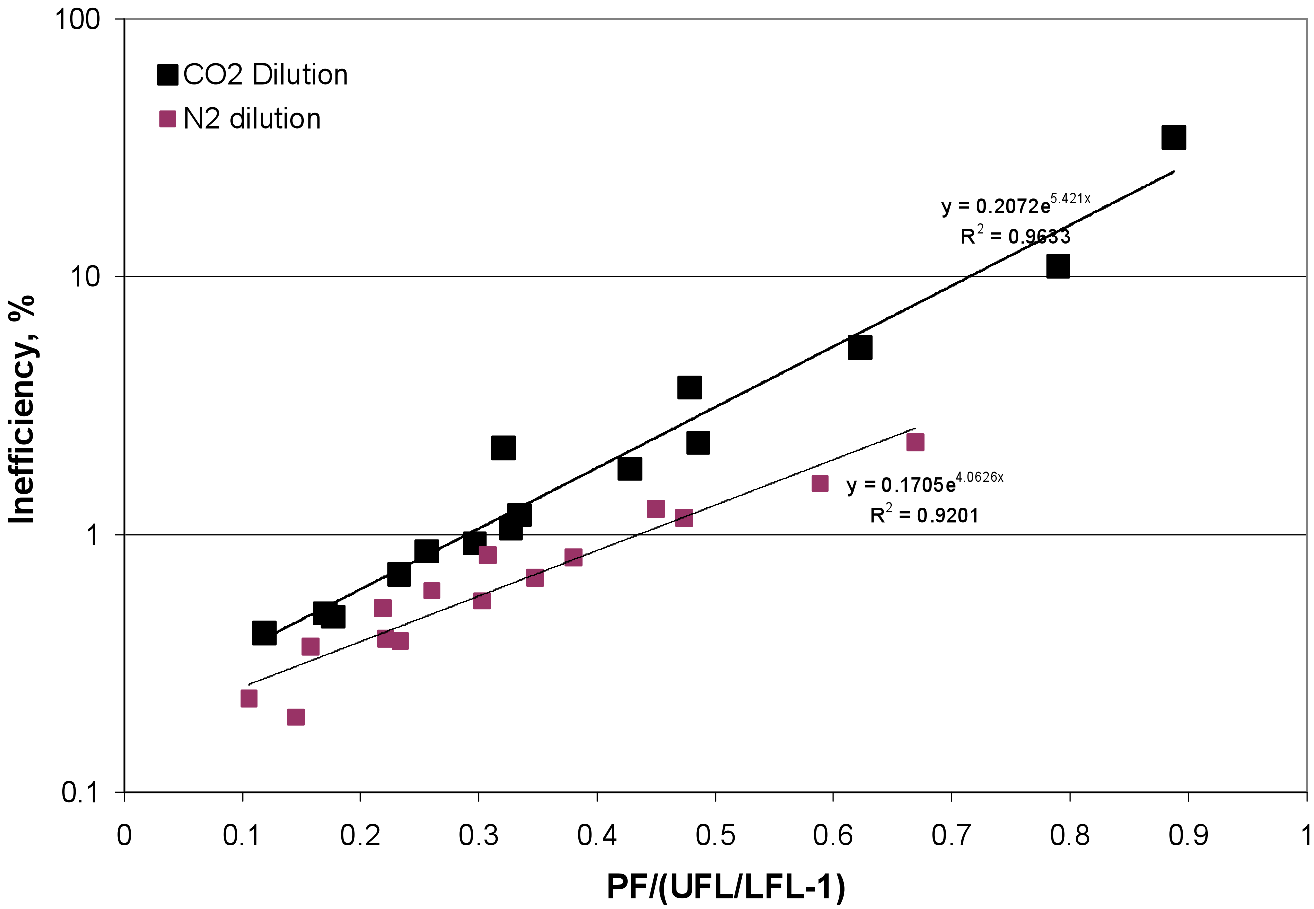
Correlating Parameters

- Two dimensionless parameters:
  - Power Factor (PF) for flow factors;
  - Mixing Factor for combustion;
- PF is Wind Power/Combustion Power

$$\left(\frac{\rho_a D_p U_w^3}{\dot{V}_f LHV_V} \right)^{1/3}$$

- Mixing Factor (UFL-LFL)/LFL

Correlation of Wind and Dilution



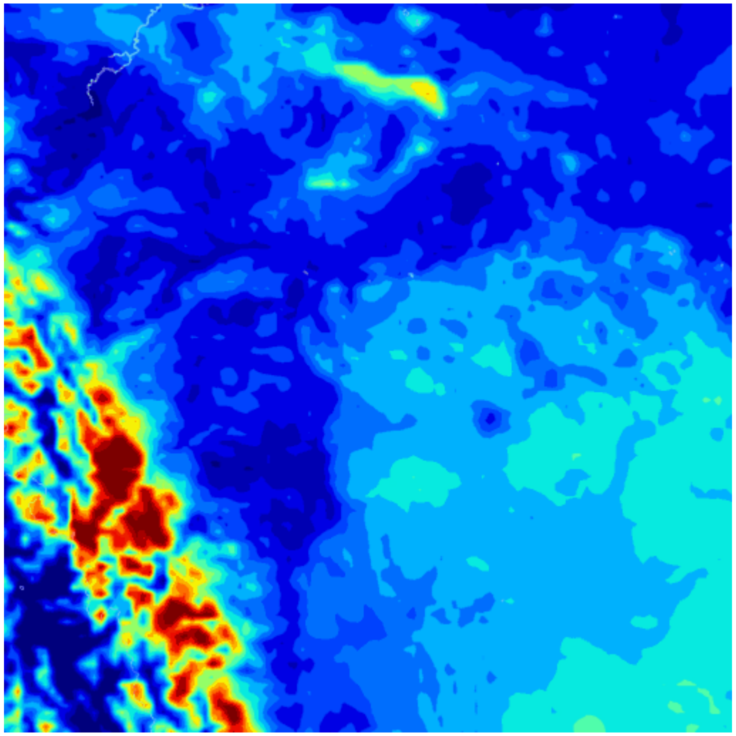
Correlation incorporates pipe size, wind speed, fuel rate, heat content and flammability limits

Implications for Biogas

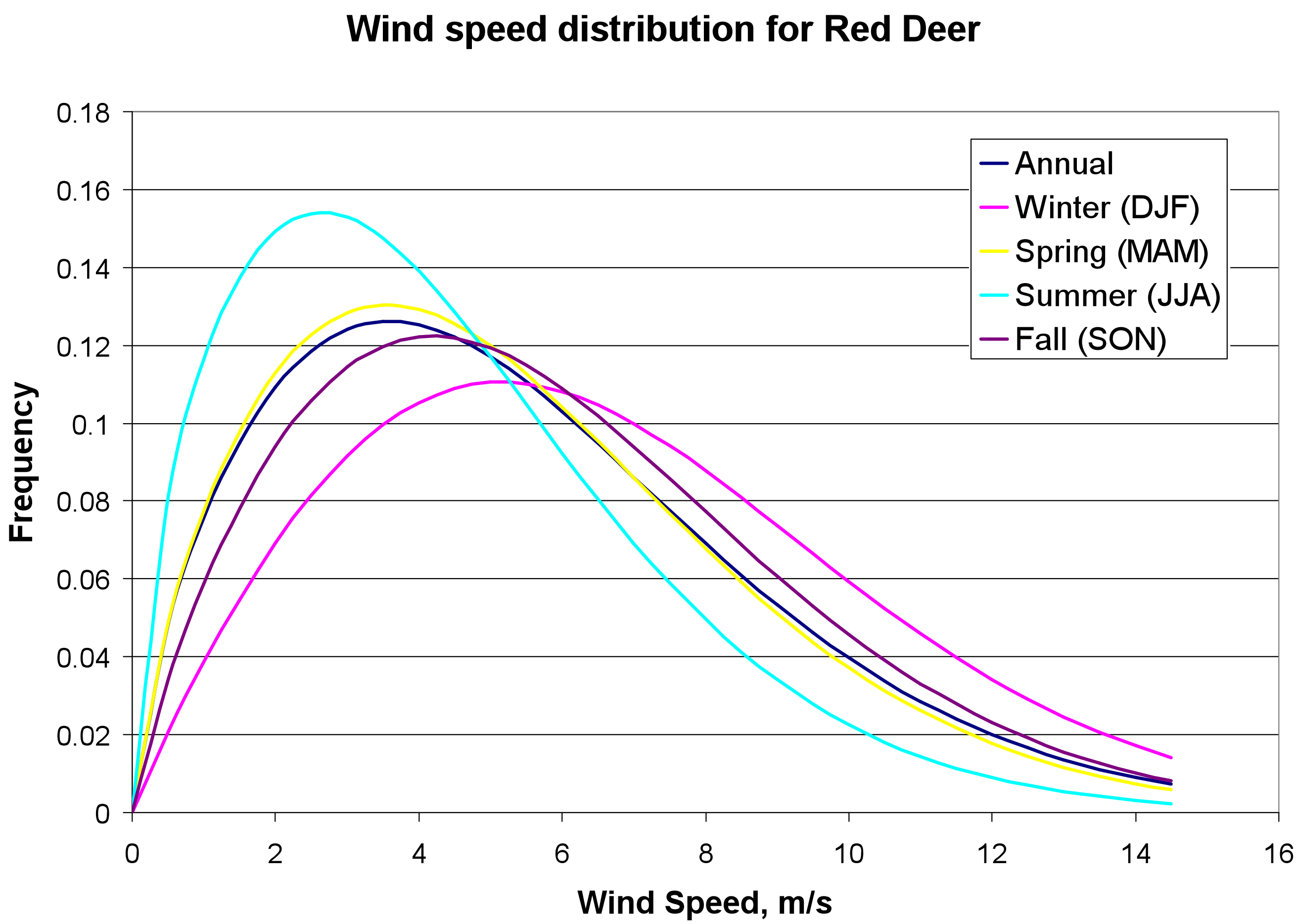
- CO_2 dilution has stronger effect than N_2
  - On stability
  - On conversion efficiency
- Significant inefficiency due to wind.
- Energy content threshold of 200 BTU/scf does not guarantee 98% efficiency.
- Have a correlation incorporating the effects of wind, flare gas rate, pipe diameter, and dilution.

Estimating Annual Emissions

- **Wind speed data available for Canada from Canadian Wind Atlas (http://www.windatlas.ca/en/index.php)**
- **Have Weibull distribution as a convenient representation.**
- **Take inefficiency curve and wind distribution to calculate annual average emissions.**



Distribution of Wind Speed



Lower wind speed in summer.

Design and Operation of Flare

- Enclosed flares best; elevated flares okay.
- Need flare sized to have good exit velocity.
- Best if gas flow variation is small
  - eg., spring empty instead of fall empty.
- Flame detection has to account for wind effects (multiple TC).

Conclusion

- Current estimation of flare efficiency based on work not related to biogas.
- Local wind conditions are important.
- Enclosed flares are best, but expensive.
- Elevated flares good enough (98% MDE) if:
  - sufficient exit velocity.
  - local wind speeds not too high.
  - methane 50%-v or better.

Conclusion

- **Annual emissions easily estimated from wind speed distribution (Weibull) and inefficiency curve for biogas (methane/CO_2 mixture).**

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