# Pilot Plant Testing of Piperazine (PZ) with High T Regeneration

Gary T. Rochelle (PI) & Eric Chen
The University of Texas at Austin

Katherine Dombrowski (PM), URS

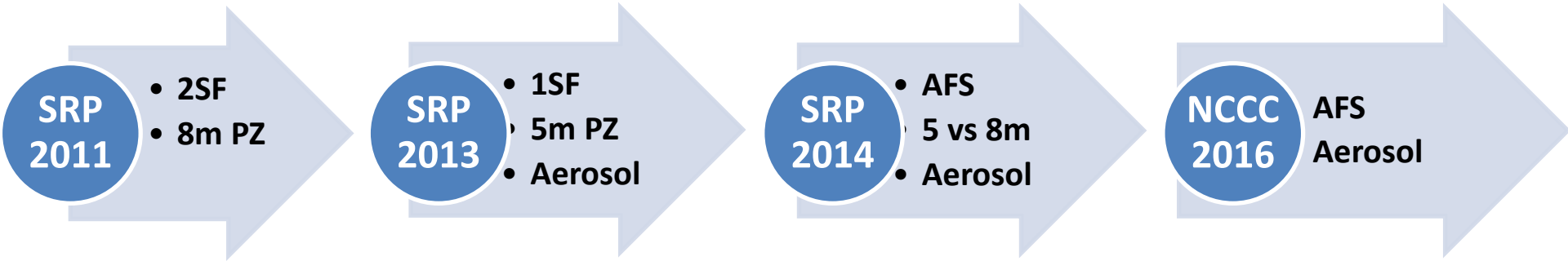
Andrew Sexton (TE), Trimeric

Bruce Lani, DOE PM

# Objective is to demonstrate PZ with advanced regeneration at 150°C in coal-fired flue gas

| | |
|---|---|
| PZ | • Optimize process<br>• Demonstrate solvent robustness |
| Regeneration | • Advanced flash stripper (AFS) |
| Aerosols | • Formation and characterization<br>• Control |

# Phased testing at UT SRP and NCCC to optimize PZ absorption/regeneration




Completed | Completed | In Progress | Pending SRP 2014 Results

# Budget Period 1

| | |
|---|---|
| $1.65 M | Federal Share |
| $0.92 M | Cost Share |
| $ 2.57 M | Total BP1 |

**Cost share by $CO_2$ Capture Pilot Plant Project (C2P3)**

EPRI ELECTRIC POWER RESEARCH INSTITUTE

LG&E KU

B&W thebabcock&wilcoxcompany

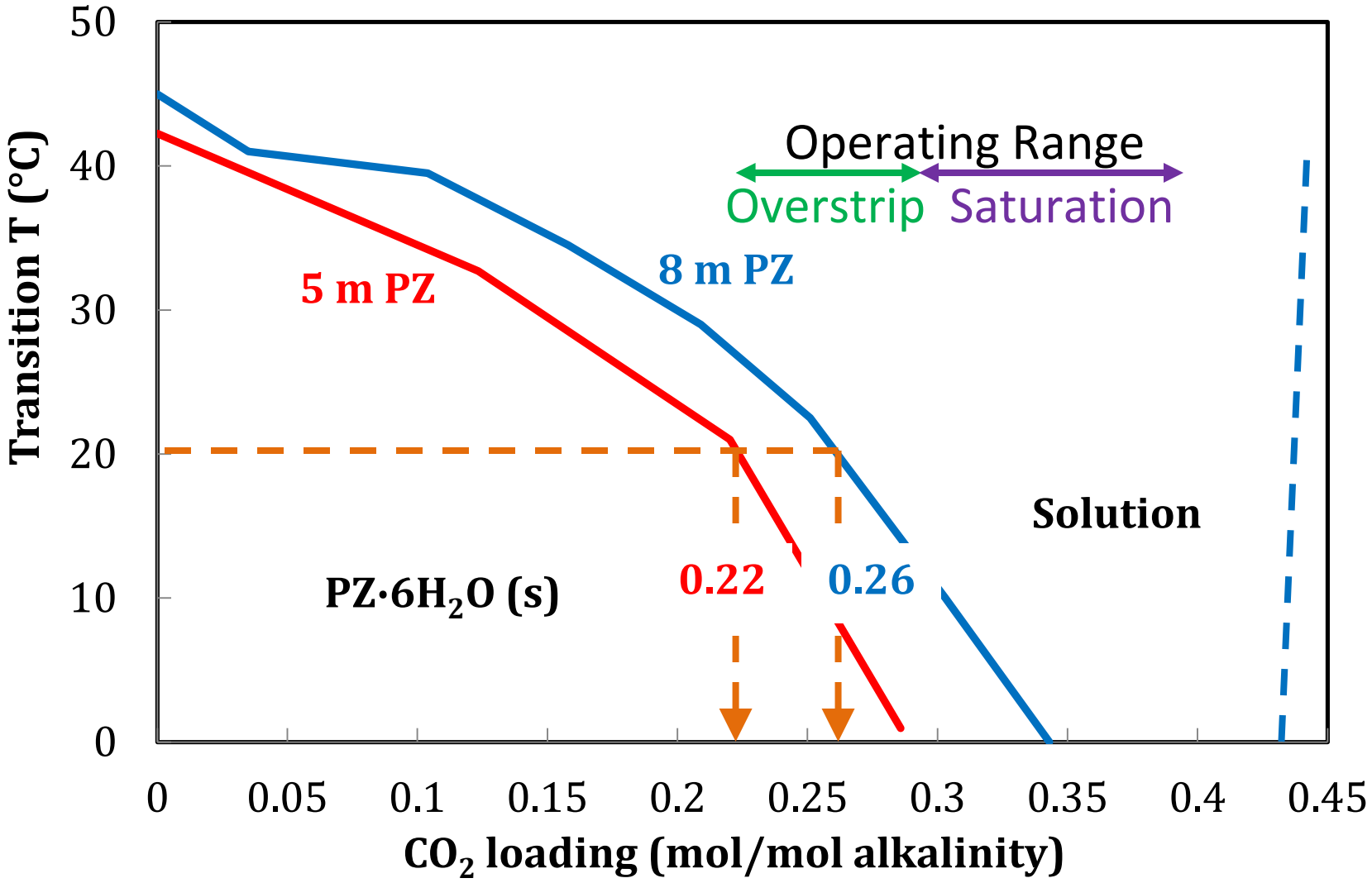
Luminant

SOUTHERN COMPANY

Chevron Human Energy

# 5m Piperazine is a Superior Solvent

# Solubility Window for 5 m & 8 m PZ



# Piperazine: Superior Energy Performance

| Amine | m | $k_g'_{avg}$*1e7 | $\mu$ | $\Delta C_\mu$ | $T_{max}$ |
|---|---|---|---|---|---|
| | | mol/s·Pa·m$^2$ | cP | mol/kg | C |
| **PZ** | **8** | **8.5** | **11** | **0.84** | **163** |
| | **5** | **11.3** | **4** | **0.81** | **163** |
| AMP/PZ | 4_2 | 8.6 | 5 | 0.90 | 128 |
| MEA | 7 | 4.3 | 3 | 0.67 | 121 |
| MDEA/PZ | 5_5 | 8.5 | 13 | 0.91 | 117 |

# Absorber Performance

## 40°C Intercooling

| | 5 m PZ | 8 m PZ |
|---|---|---|
| **Lean Ldg at solid limit (mol $CO_2$/mol alk)** | 0.22 | 0.26 |
| **Rich Loading (mol $CO_2$/mol alk.)** | 0.40 | 0.40 |
| **L/G (mol/mol)** | 3.03 | 2.55 |
| **Equivalent Work (kJ/mol $CO_2$)** | **36.0** | **36.3** |
| **Packing Required ($m^2$/mol $CO_2$)** | **126** | **298** |

# PZ: superior solvent management

## Resistant to oxidation

- Cyclic : PZ (160C)) = 1.3  MEA (120C) = 4.7  mM/hr

## Volatility  just right

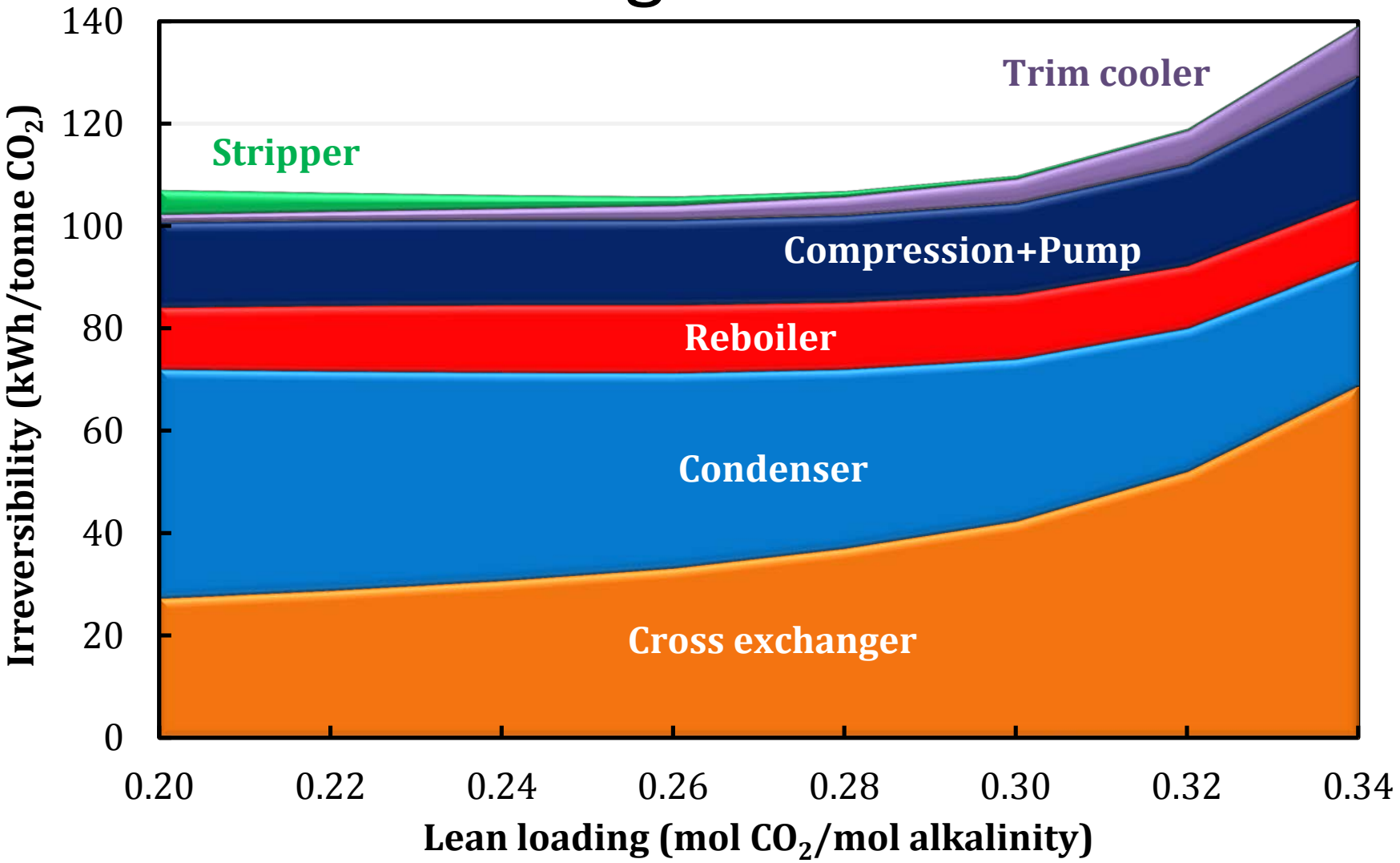
- At lean absorber: PZ = 8  MEA=30  ppm
- Thermal reclaiming removes nonvolatile impurities
- PZ & MEA may condense out as aerosols in absorber

## Nitrosamine manageable

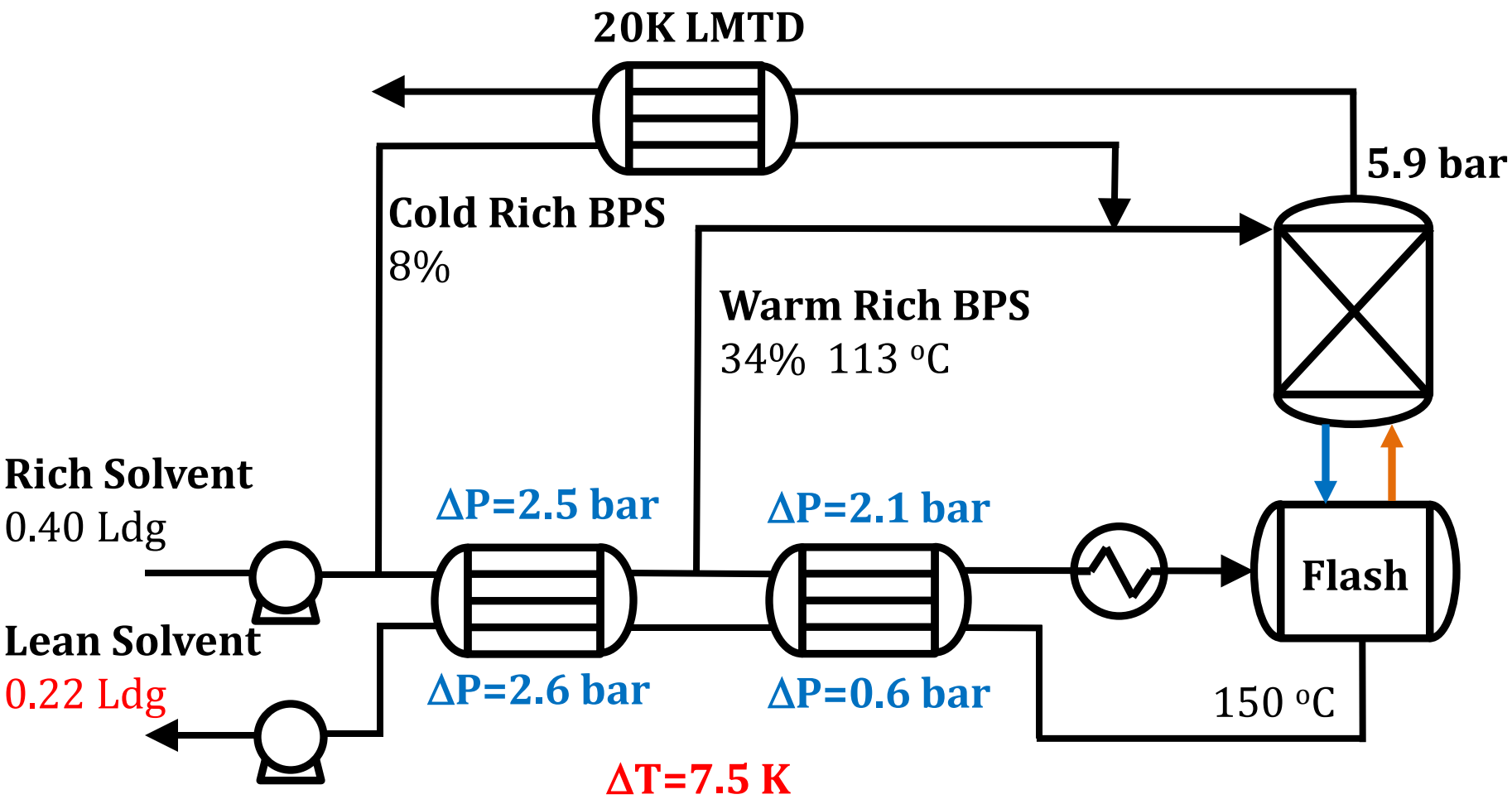
- PZ + $NO_2/NO_2^-$ → mononitrosopiperazine (MNPZ)
- Decomposes at 150°C giving 1 mM MNPZ at SS

The Advanced Flash Stripper (AFS) minimizes Energy Use and Capital Cost.

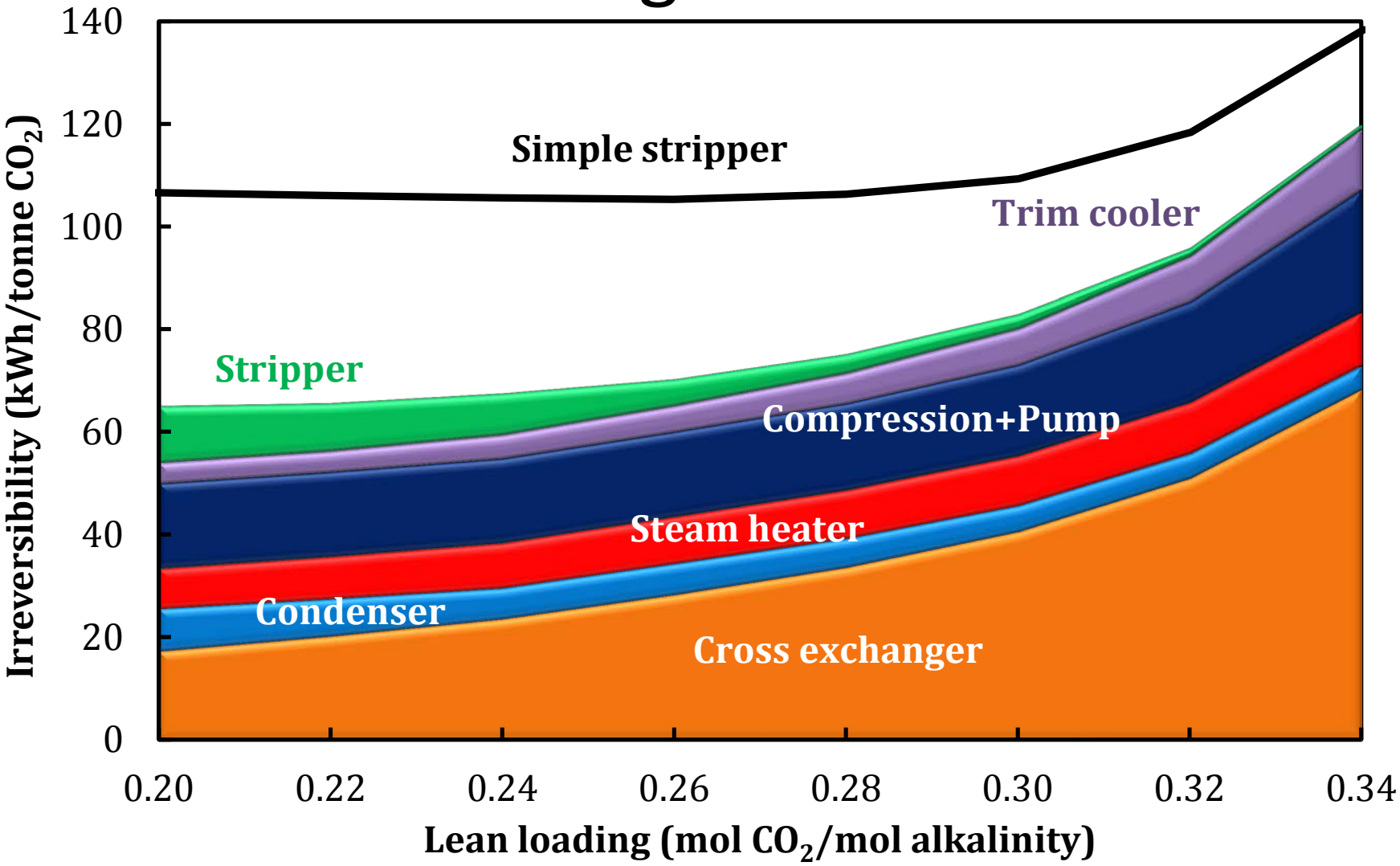
# Irreversibility of simple stripper using 5 m PZ



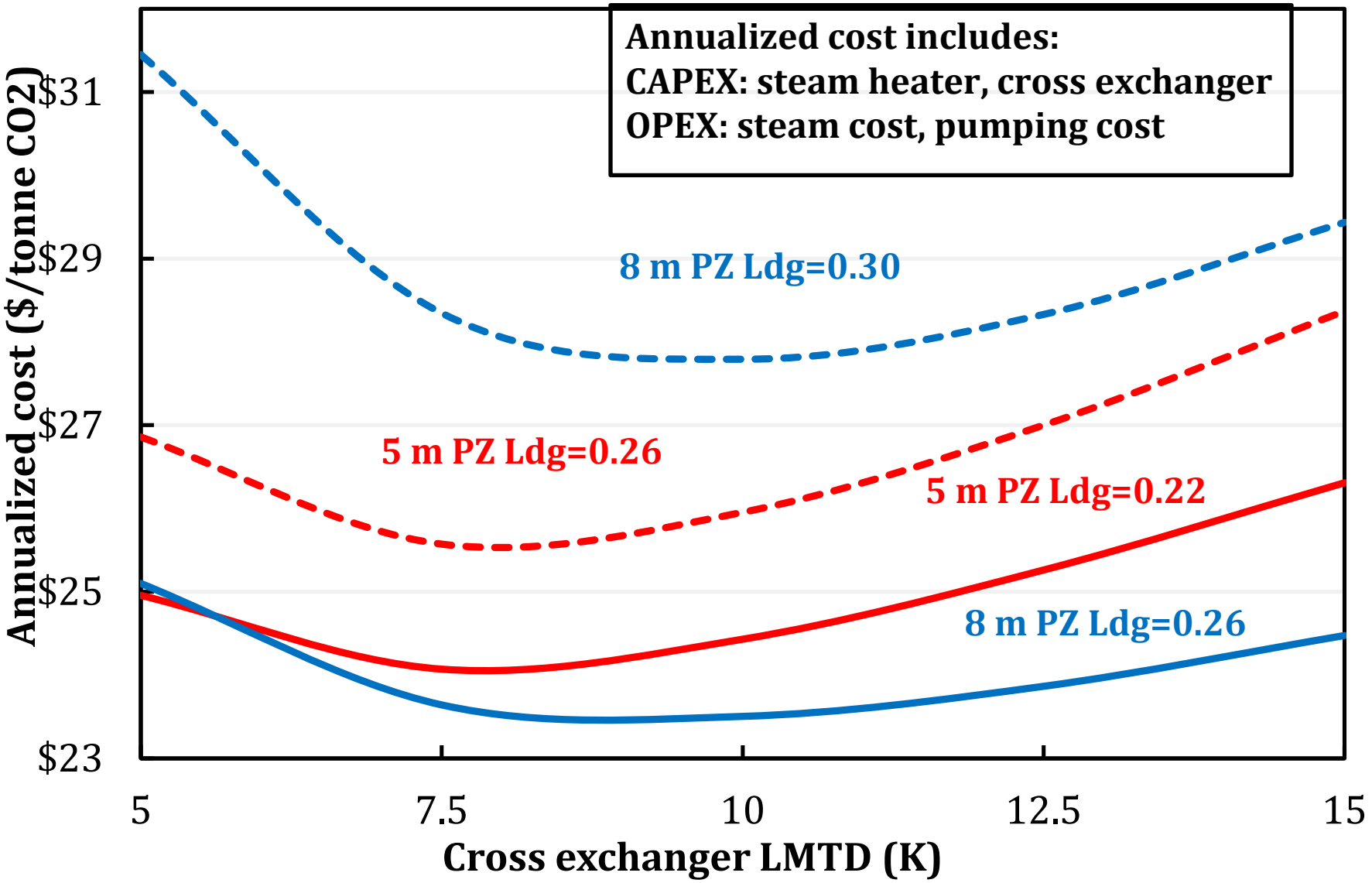
# Advanced flash stripper using 5 m PZ



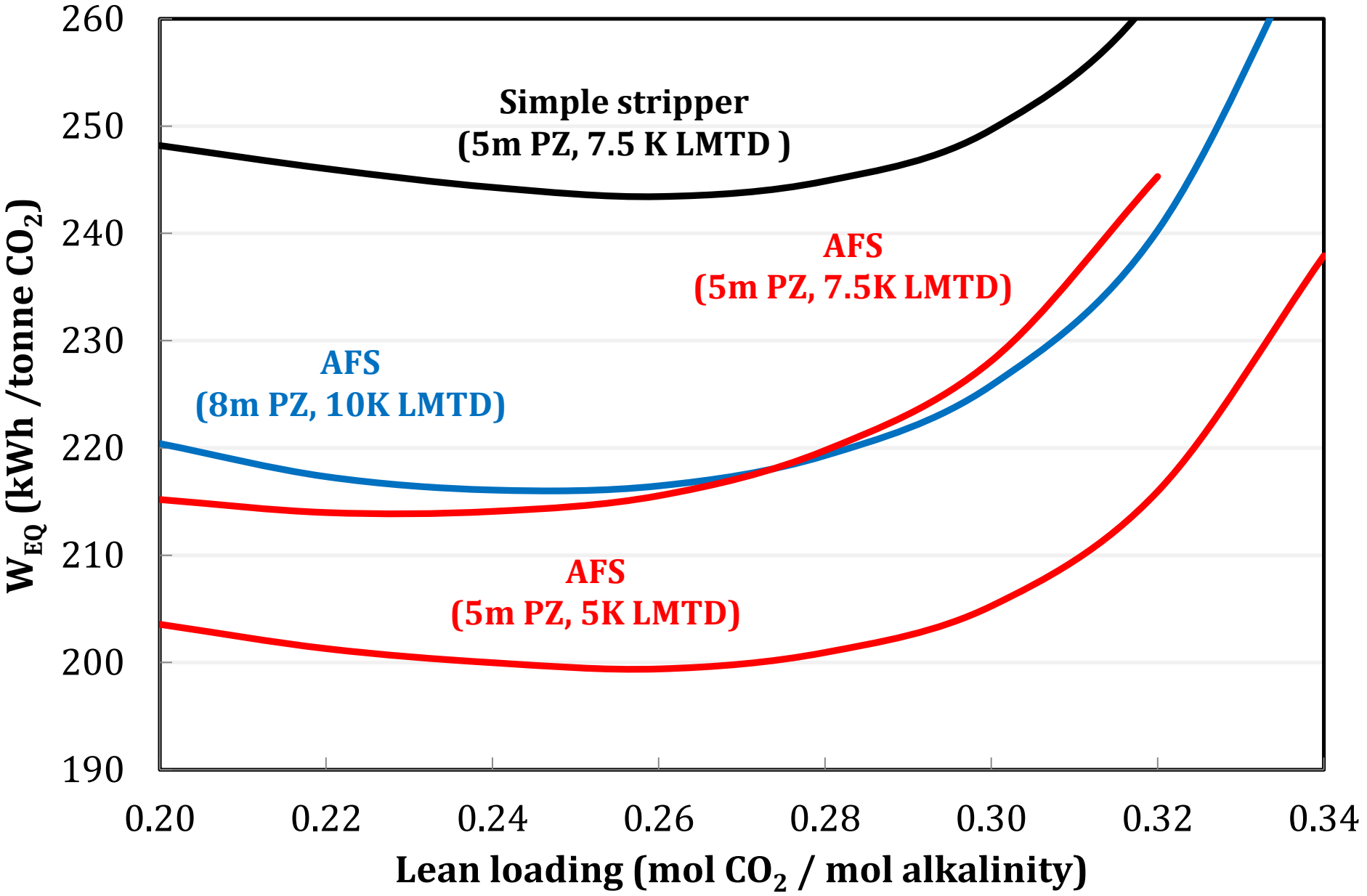
# Irreversibility of AFS using 5 m PZ



# Total Annualized Cost of Regeneration (Does not include absorber)



# Total Energy



AFS saves 10% over SS

($/metric ton $CO_2$ Captured, not rigorous DOE method)

(593 MWe Gross)

| | MEA-SS | PZ-SS | PZ-AFS |
|---|---|---|---|
| Energy Derating ($MW_e$) | 145 | 97.5 | 90.1 |
| CAPEX | 22 | 22.1 | 19.4 |
| OPEX | 37 | 25.1 | 23.2 |
| Cost of $CO_2$ Capture (excluding TS&M) | 59.5<br>(1.00) | 47.2<br>(0.79) | 42.6<br>(0.72) |

Amine Aerosols can be measured
by FTIR and
Phase Doppler Interferometer (PDI).

# Amine aerosols cause high amine emissions

Nucleation sites in flue gas

- $SO_3/H_2SO_4$
- Submicron fly ash
- $SO_2$/amine

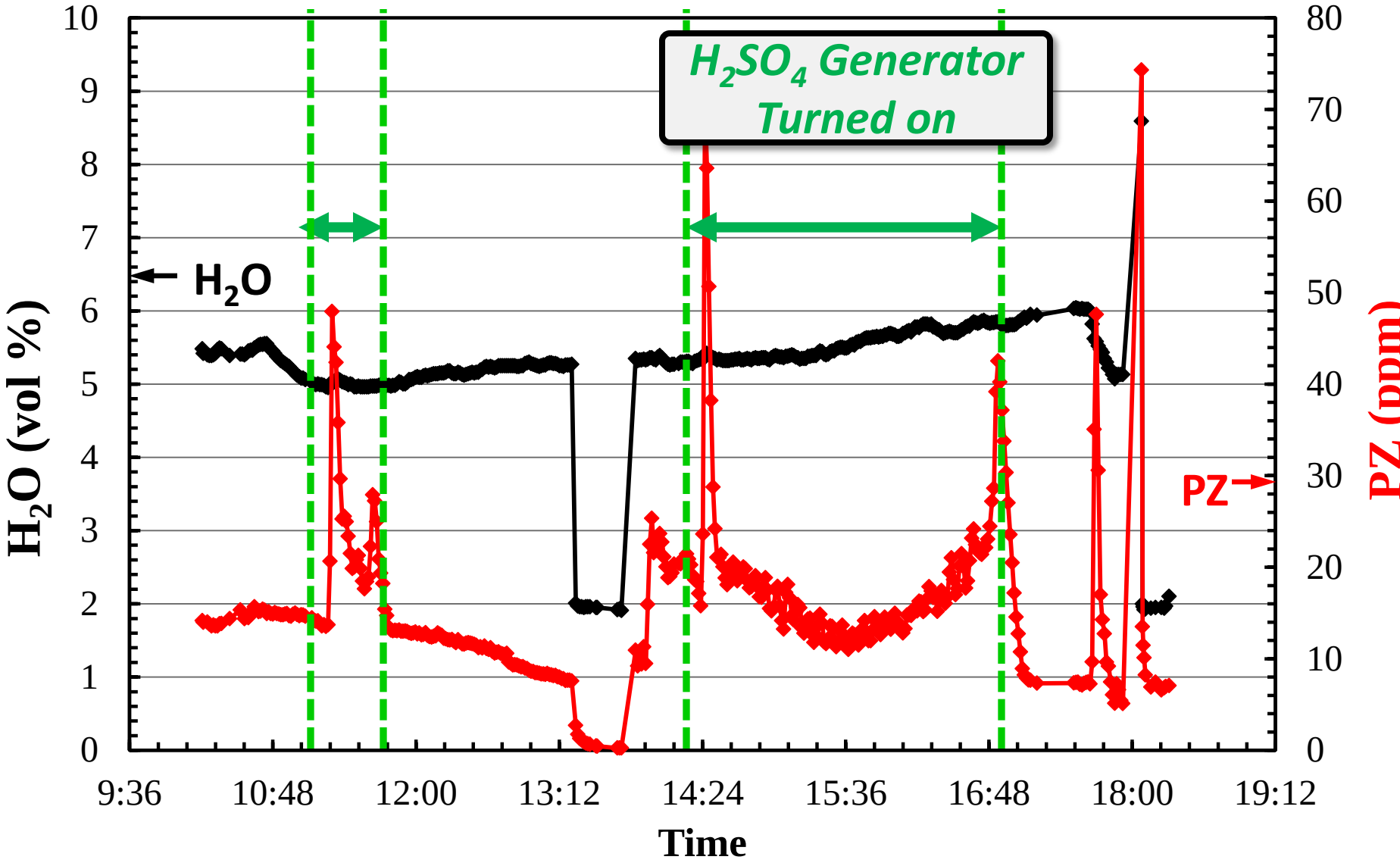
+ Amine condensation

- Amine/$CO_2$/$H_2O$ from solvent to aerosol

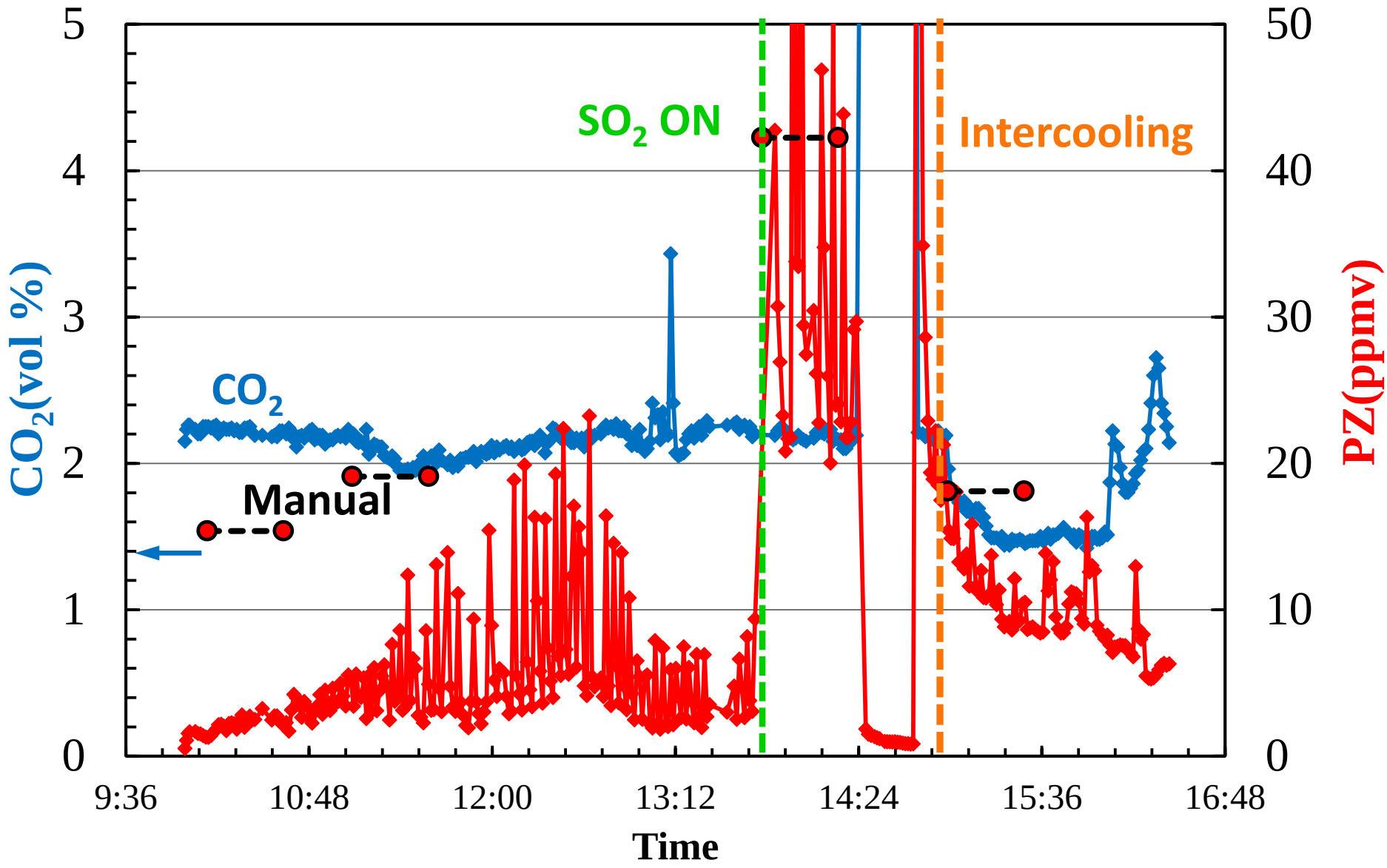
+ Poor collection of small drops in water wash

= Unacceptable amine emissions

# Effect of H2SO4 Injection
# FTIR Absorber out



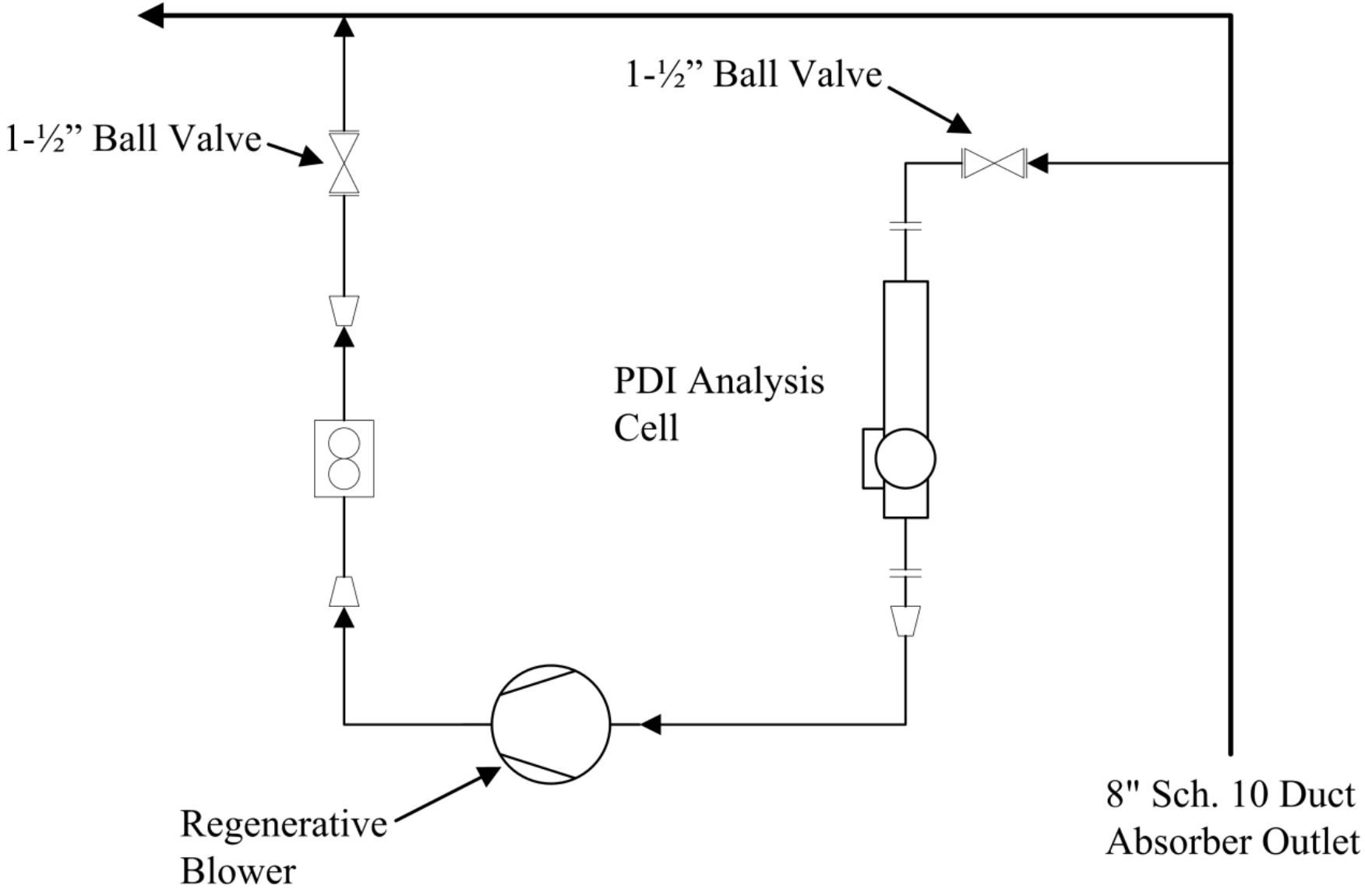
# Effect of 25 ppm $SO_2$ on PZ Aerosol



# Phase-Doppler Interferometer (PDI)

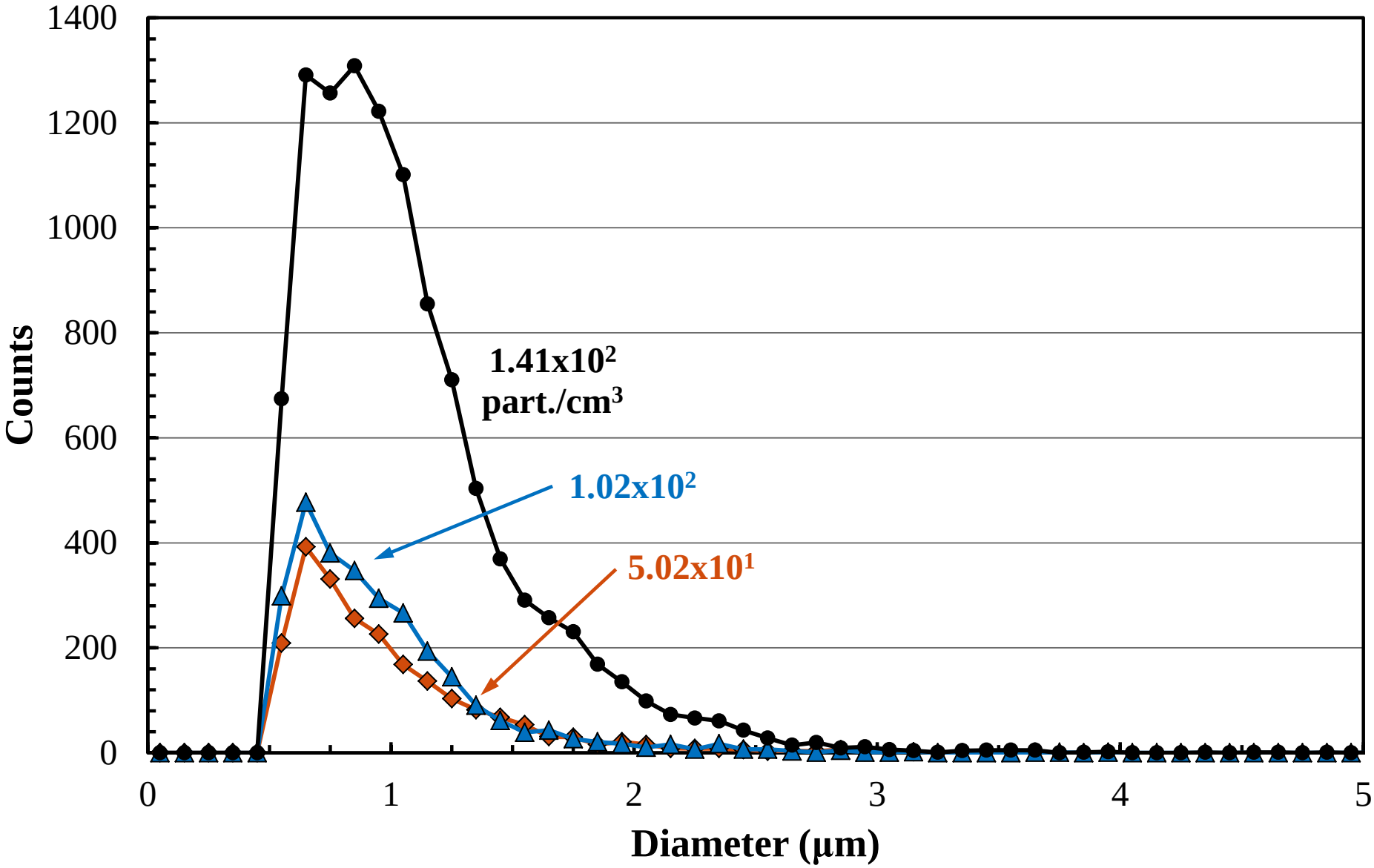
## Size & concentration: 0.5 – 10 µm up to $10^6$ particle/$cm^3$

## 2G Bypass Extractive Sampler (tested 11/13)



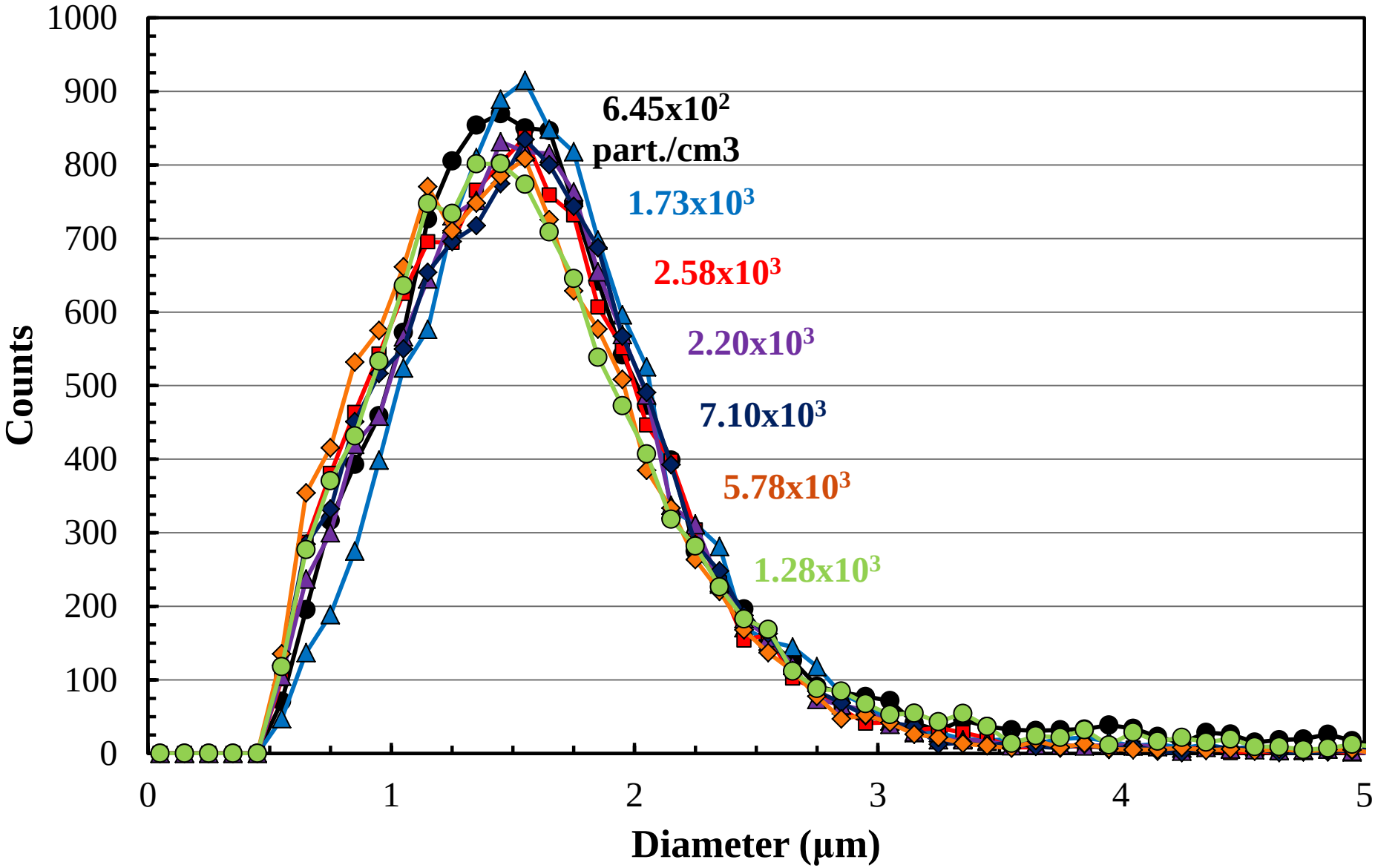
# PDI at Absorber Outlet – Startup

## (11/22/2013)



# Absorber Outlet – Steady-State

## (LVI $H_2SO_4$: 11/22/2013)



# Modifications for 3G PDI



- Use custom transmitter/receiver
  - to see down to 0.1 µm
- Use sapphire heated windows
  - to prevent liquid sheeting
- Set windows in flow body
  - To minimize wall geometry effects

# Aerosol and AFS Test Plans for SRP 2014

- Energy performance of AFS
- Energy performance of 5 m PZ vs. 8 m PZ
- Aerosol formation
  - Add $SO_2$ and $H_2SO_4$ to the inlet gas
  - Use 3G PDI purchased by NCCC
  - Manual and FTIR measurements of amines
  - Impingement tray at top of the absorber

# Conclusions

- 5 m PZ is a superior, demonstrated solvent.
- The advanced flash stripper provides 10% better energy performance for PZ and other solvents.
- Aerosol measurements by FTIR and PDI will quantify aerosol emissions for further control.

- **Acknowledgement:** "This material is based on work supported in part by the Department of Energy under Award Number DE-FE0005654."


# GHGT-12

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