

# **System for the Removal of the NO<sub>x</sub> and SO<sub>2</sub> from Incinerator Effluents**

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# Overview

- **Need for waste incineration in long term life support systems.**
  - Inhabitation of Lunar or Martian surface.
- **Overview of waste treatment system.**
  - Hardware for particulate removal.
  - SO<sub>2</sub> adsorption in fixed bed reactor.
  - HC oxidation.
  - NO control by oxidation and wet scrubbing.
- **Initial system design.**

# Waste Incineration in Long Term Life Support Systems

- **Eliminates the hazards and difficulties associated with storing wastes.**
- **Converts waste to carbon dioxide, water, and ash, which are used to regenerate food supply.**
- **Unfortunately, incineration also produces toxic compounds.**
  - NO and NO<sub>2</sub> (NO<sub>x</sub>).
  - SO<sub>2</sub>.
  - CO, hydrocarbons.

# **NO<sub>x</sub> and SO<sub>2</sub> Generation in Combustion**

- **At high temperatures, thermodynamics strongly favor NO and SO<sub>2</sub>.**
- **At these temperatures, kinetics are rapid.**
- **Sources of nitrogen are the air used in combustion and nitrogen containing compounds in material burned.**
- **Sulfur comes from material burned.**

# Incinerator Effluent Composition\*

Component	Concentration	Kg/h
N <sub>2</sub>	34%	4.22
O <sub>2</sub>	6%	0.19
CO <sub>2</sub>	10%	1.06
H <sub>2</sub> O	49%	4.26
HC (CO)	1%	0.03
SO <sub>2</sub> <sup>†</sup>	100 ppm	0.0005
NO <sub>x</sub>	400 ppm	0.0005
Ash		0.001

Total design flow = 150 liters/min

\*Fisher et al. 1998, SAE 981758; <sup>†</sup> Measured SO<sub>2</sub> < 1 ppm.

# SBIR Phase II Project

- **Design and construct system to control all hazardous components from NASA Ames incinerator effluent.**
  - Ash, SO<sub>2</sub>, HC, NO<sub>x</sub>.
- **Test system on fluidized bed combustor at NASA Ames Research Center.**

# System Components

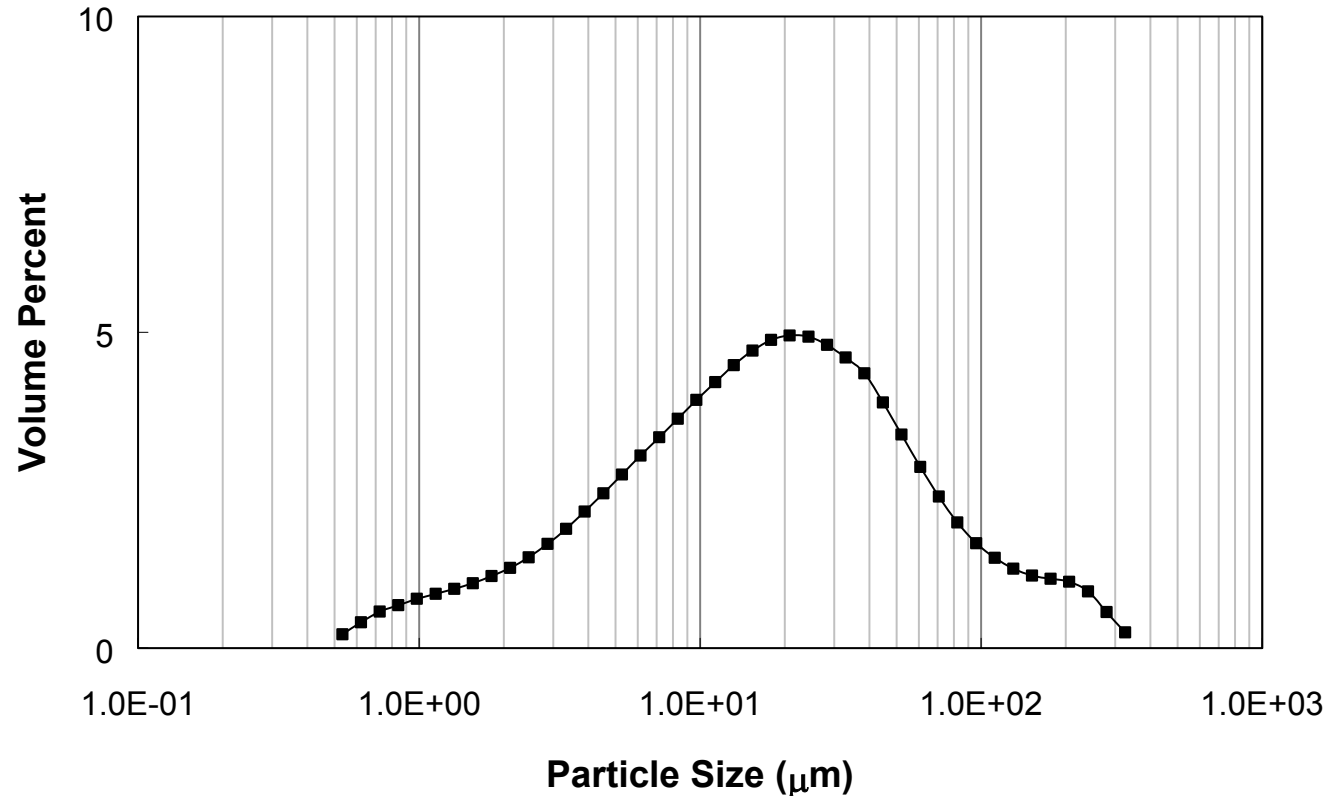
- Cyclone to remove 99% of particulate.
- Heat exchanger to reduce effluent temperature to approximately 500°C.
- Filter to remove the remaining ash particles.
- Fixed bed SO<sub>2</sub> sorbent at 450°C.
- HC (CO) oxidation catalyst at 400°C.
- NO oxidation catalyst at 260°C.
- NO<sub>2</sub> scrubber and H<sub>2</sub>O knockout at 25°C.



# Requirements of Cyclone

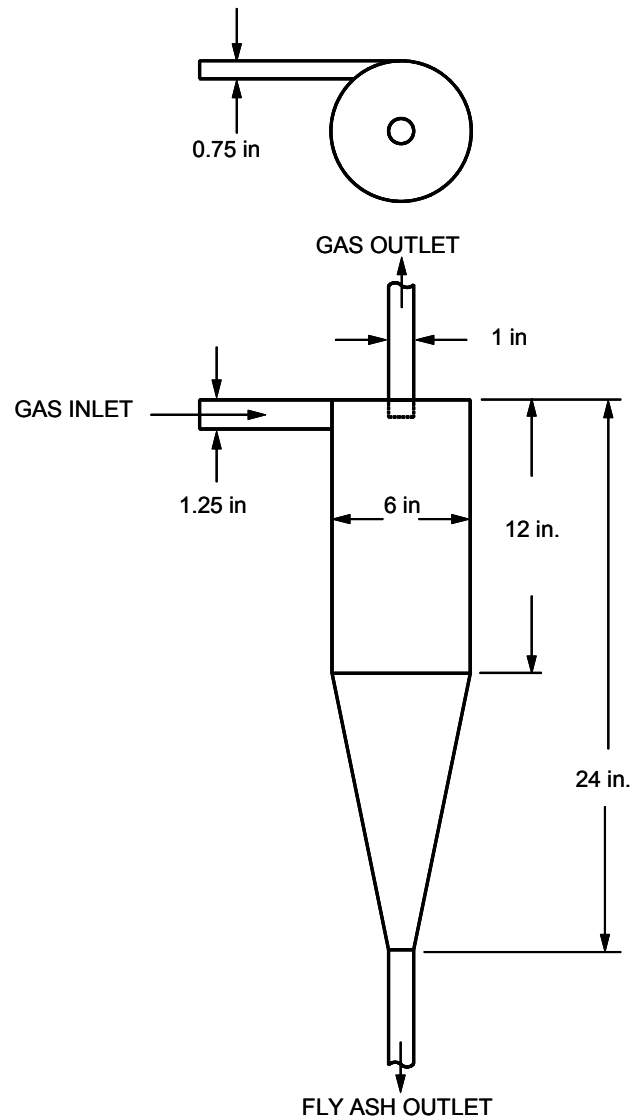
- **Withstand temperatures up to 1000°C.**
- **99% particle removal efficiency down to 1 micron in diameter.**
- **Less than 2.5-in pressure drop at 150 slpm flow.**
- **Easy to remove particulate.**

# Particle Size Distribution of Ash from NASA Incinerator



99% of the ash volume consists of particles > 1 micron in diameter

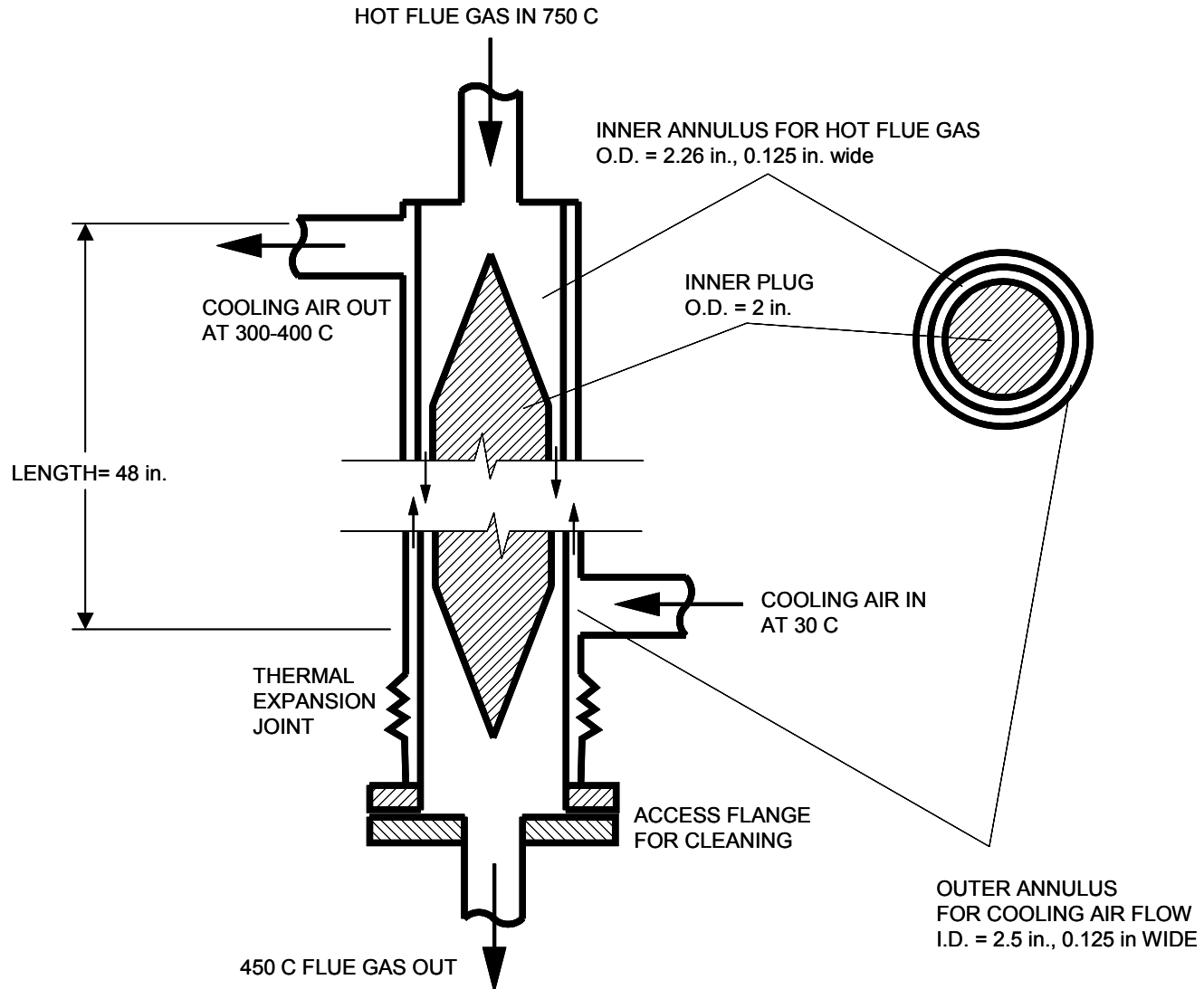
# Cyclone Design will Collect 99% of the Ash



# Heat Exchanger Requirements

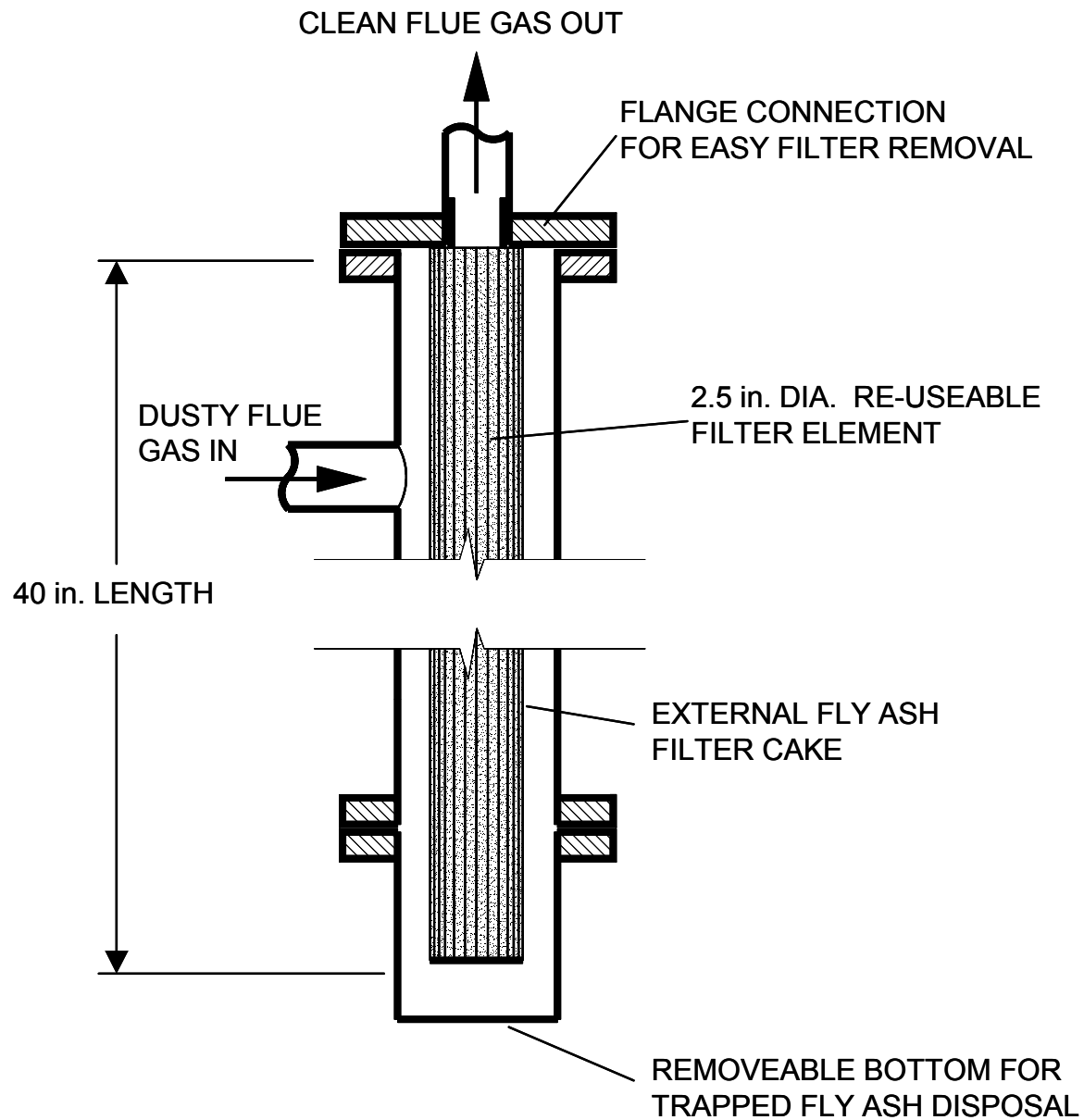
- **Must reduce gas temperature from 1000°C to 500°C in a small volume.**
- **Less than 2-in H<sub>2</sub>O pressure drop at design flow rate of 150 SLPM.**
- **Low maintenance.**

# Heat Exchanger Design



# Requirements for the Particulate Filter

- **High capacity.**
- **Low pressure drop at high loadings.**
- **Robust.**
- **Withstand temperatures up to 450°C.**
- **Easy to clean.**



# Sulfur Dioxide Removal

- **Commercial methods have been developed to remove SO<sub>2</sub> from flue gas for coal fired power plants - for example:**
  - Wet scrubbing (e.g CaCO<sub>3</sub> slurries)
  - Dry scrubbing (e.g Na<sub>2</sub>CO<sub>3</sub> injection)
- **Our choice**
  - Fixed Bed - Na<sub>2</sub>CO<sub>3</sub> absorber



# SO<sub>2</sub> Removal with a Fixed Bed of Na<sub>2</sub>CO<sub>3</sub>

- **Advantages**

- Mechanically simple
- High capacity (0.6g SO<sub>2</sub>/g Na<sub>2</sub>CO<sub>3</sub> from reaction stoichiometry)
- Reaction is thermodynamically irreversible at temperatures of interest (300 - 600°C)
- Unaffected by presence of CO<sub>2</sub>

- **Disadvantages**

- Non-regenerable

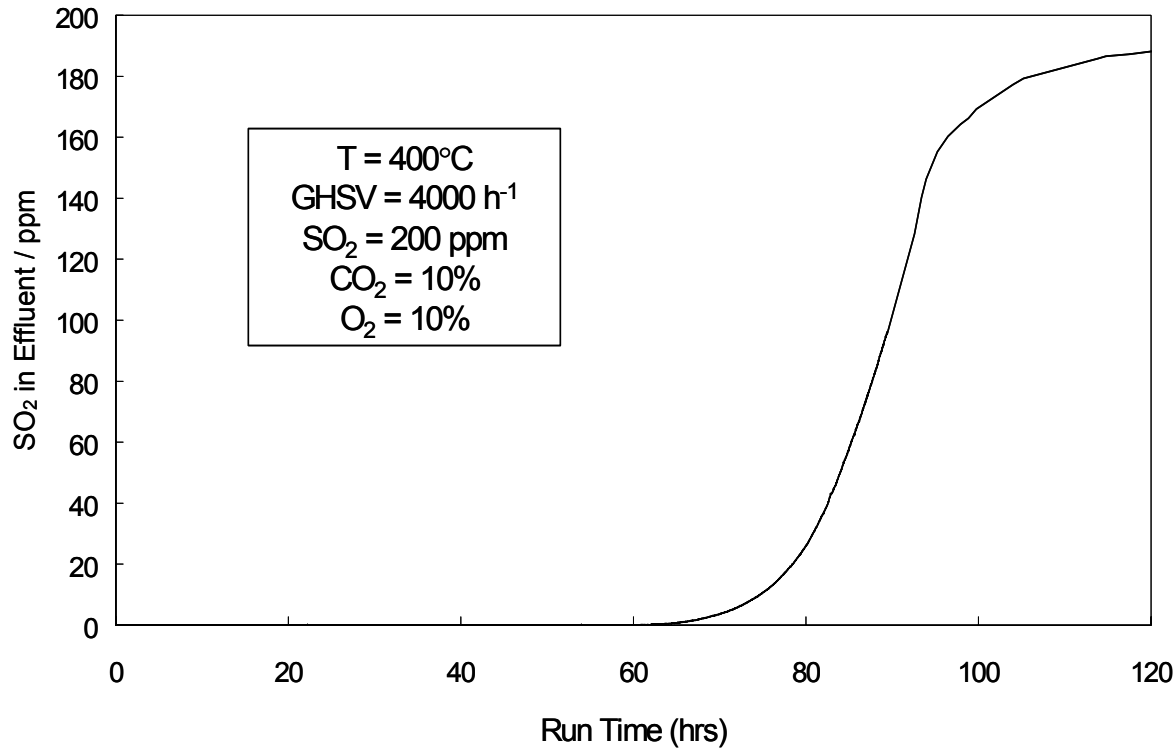
# Difficulties with Fixed Bed

- Sorbent volume increases during conversion to the sulfate.
- Packed bed will expand, rupturing vessel or increasing pressure drop.

# TDA's Approach

- **Use existing “geode” technology to develop sorbent that does not change in volume.**
- **Mix sodium carbonate with alumina binder.**
- **Pelletized sorbents were effective and did not expand.**

# Adsorption Experiments

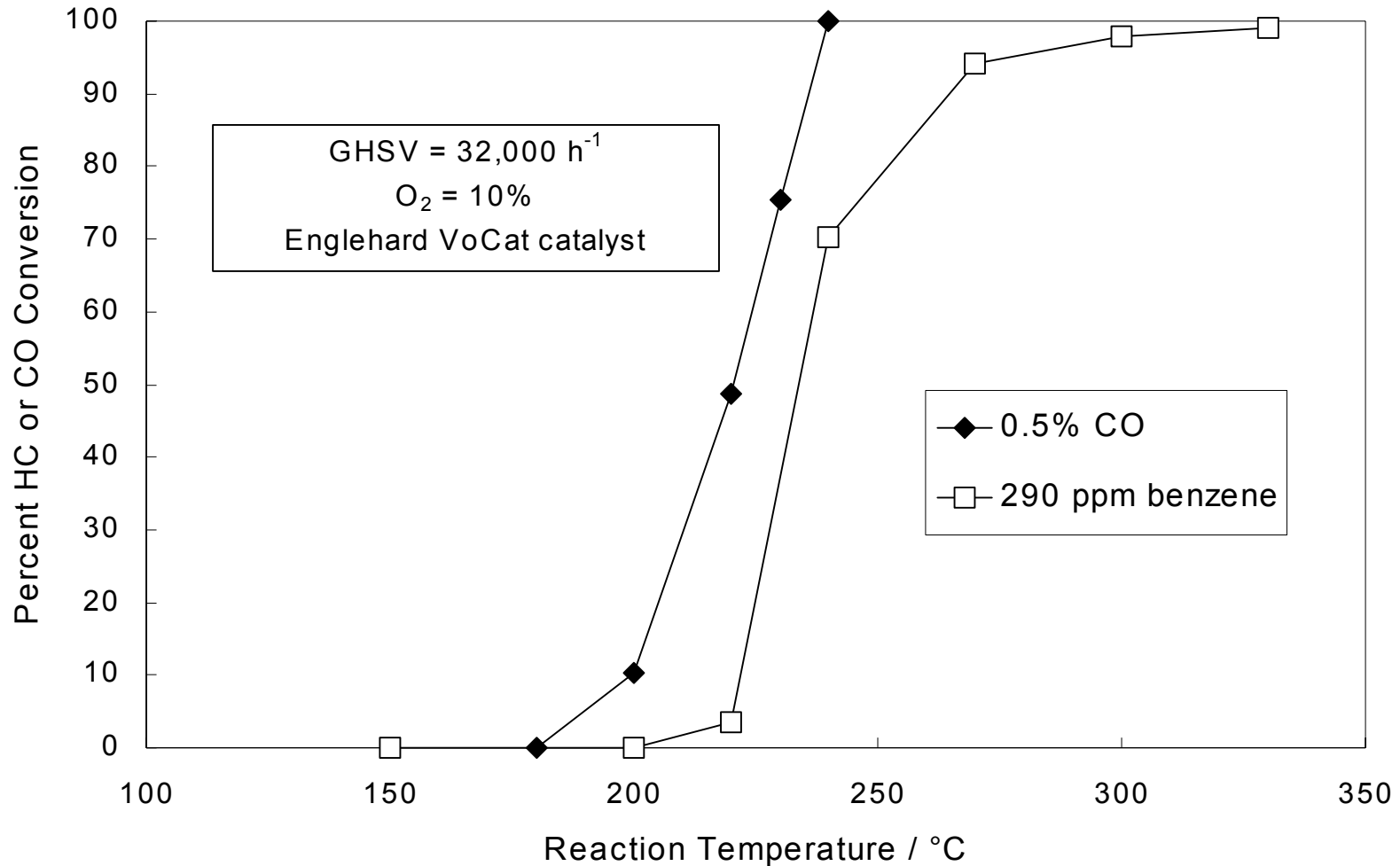


21 Wt % loading at breakthrough.

# Hydrocarbon Oxidation

- **Use existing VoCat catalyst provided by Englehard.**
- **Carried out tests to verify performance at temperature.**
- **Measured rates for CO and a less reactive hydrocarbon (benzene).**

# HC Oxidation Testing



Operation at 400°C will provide adequate reaction rates

# Current NO<sub>x</sub> Control Technology

- **Selective Reduction (catalytic and non catalytic).**
  - Reducing agent must react with NO instead of O<sub>2</sub>.
  - $3 \text{ NO} + 2 \text{ NH}_3 \rightarrow 5/2 \text{ N}_2 + 3 \text{ H}_2\text{O}.$
- **Combustion modification (reducing temperature) are only moderately effective.**
- **To date, no catalyst has been identified that is active for the direct decomposition of NO into N<sub>2</sub> and O<sub>2</sub>.**

# Problems with Selective Reduction for NO<sub>x</sub> Control

- **Reaction requires addition of ammonia.**
  - Must be present in excess to achieve high efficiency.
- **Difficult to inject so that it is well mixed prior to contacting catalyst.**
  - (Non catalytic systems suffer from poor efficiency).
- **Instrumentation required to adjust NH<sub>3</sub> injection to changing NO concentrations.**
- **Handling ammonia can be dangerous and requires pressurized tank.**

# **NO<sub>x</sub> Removal by Oxidation and Scrubbing**

- **Take advantage of excess oxygen in effluent stream to catalytically oxidize NO (90% of NO<sub>x</sub>) to NO<sub>2</sub>.**
- **Use a wet scrubber to remove NO<sub>2</sub> from the waste stream (NO has a low solubility in water and therefore cannot be scrubbed).**

# Chemical Reactions

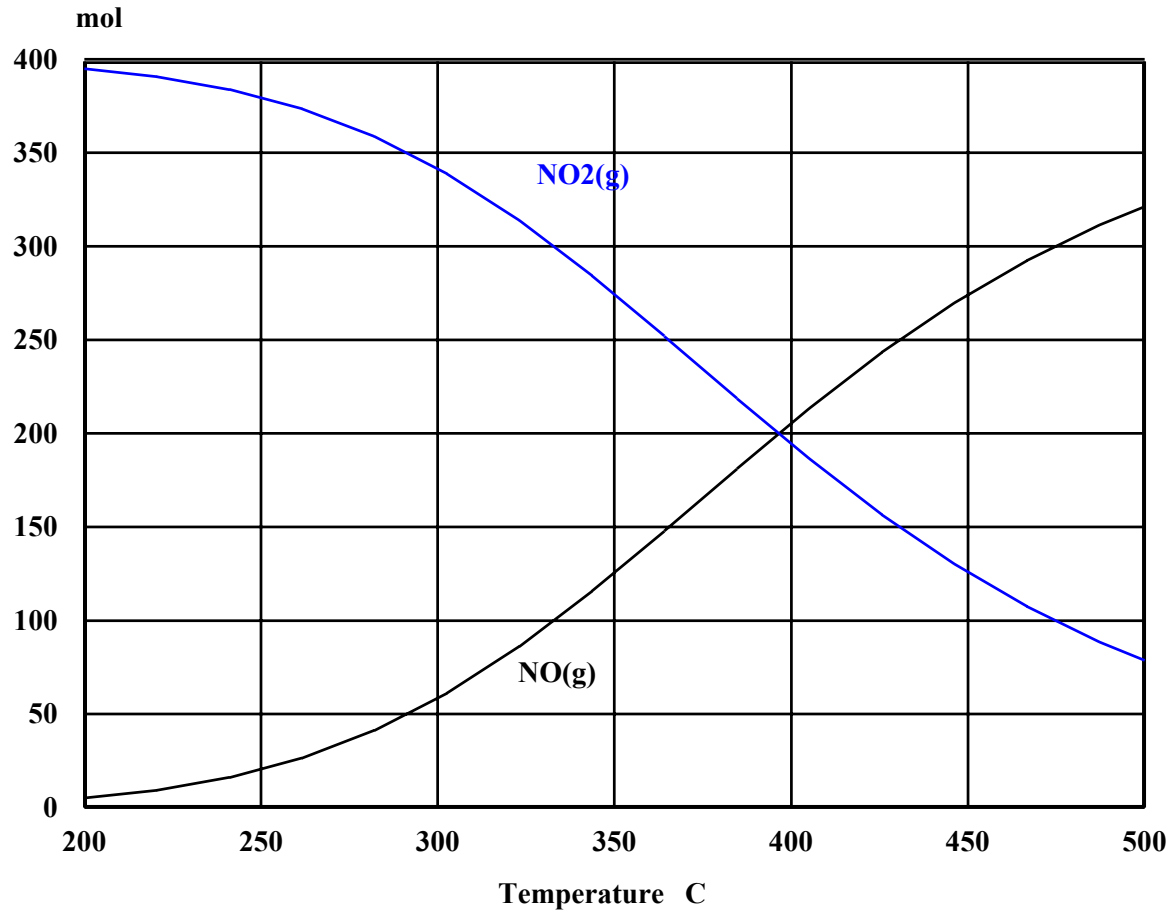
- **Oxidation**

- $\text{NO} + 1/2 \text{O}_2 \rightarrow \text{NO}_2$
- Occurs rapidly on catalyst, slowly in air.
- Must be done at temperatures below 300°C.

- **Adsorption and neutralization of  $\text{NO}_2$**

- $2 \text{NO}_2 + \text{H}_2\text{O} \rightarrow \text{HNO}_3 + \text{HNO}_2$
- Strongly favored by thermodynamics at low concentrations.
- $\text{HNO}_3 + \text{HNO}_2 + \text{Na}_2\text{CO}_3 \rightarrow \text{NaNO}_3 + \text{NaNO}_2 + \text{H}_2\text{O} + \text{CO}_2$ .

# Thermodynamics require NO Oxidation at Low Temperature



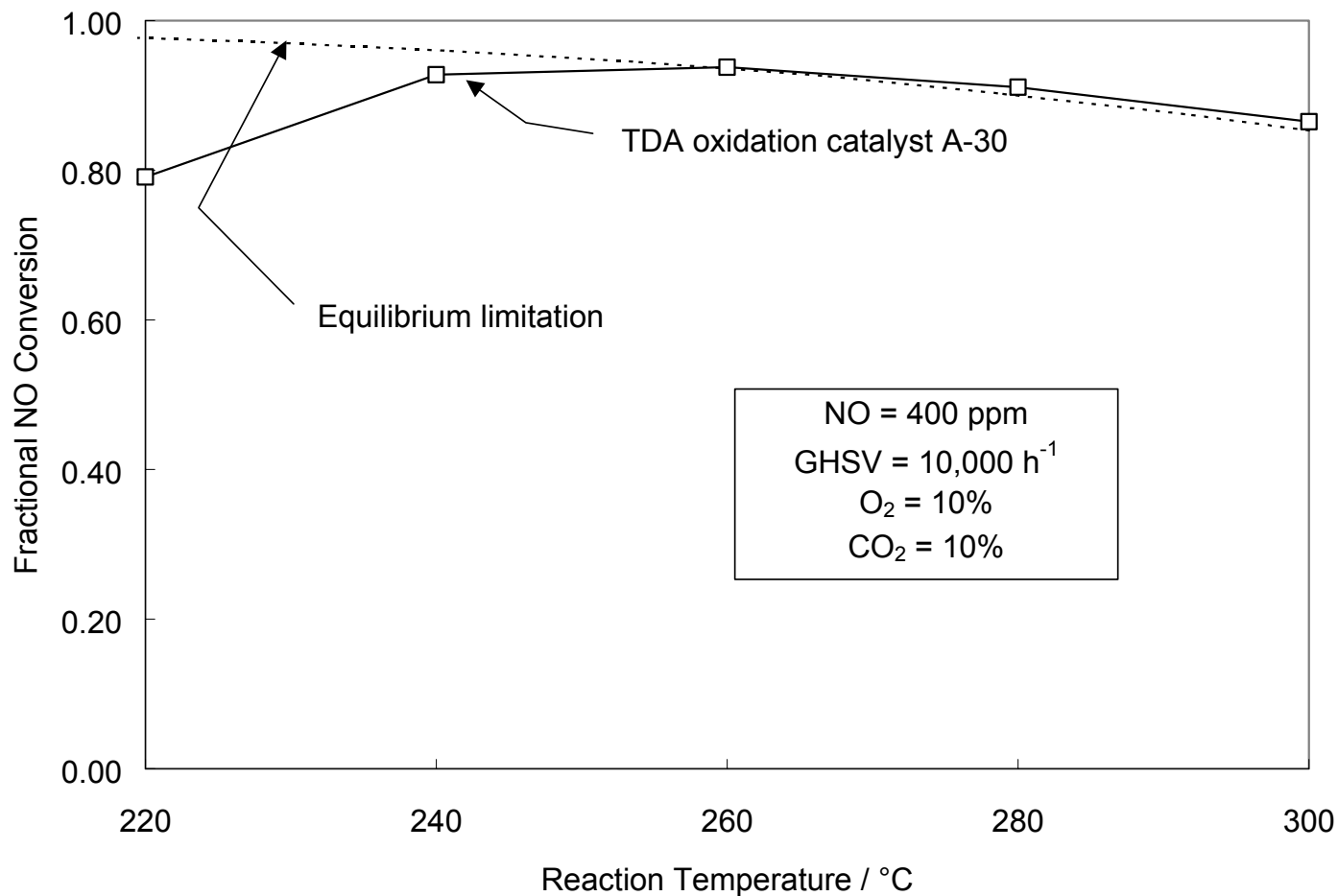
# Advantages of NO<sub>x</sub> Removal by Oxidation and Scrubbing over SCR

- Does not require addition of reactant prior to contacting catalyst.
- Does not require instrumentation to constantly adjust concentration of NH<sub>3</sub>.
- Does not require use of toxic compound in pressurized tank.
- No potential for exposing crew to ammonia.

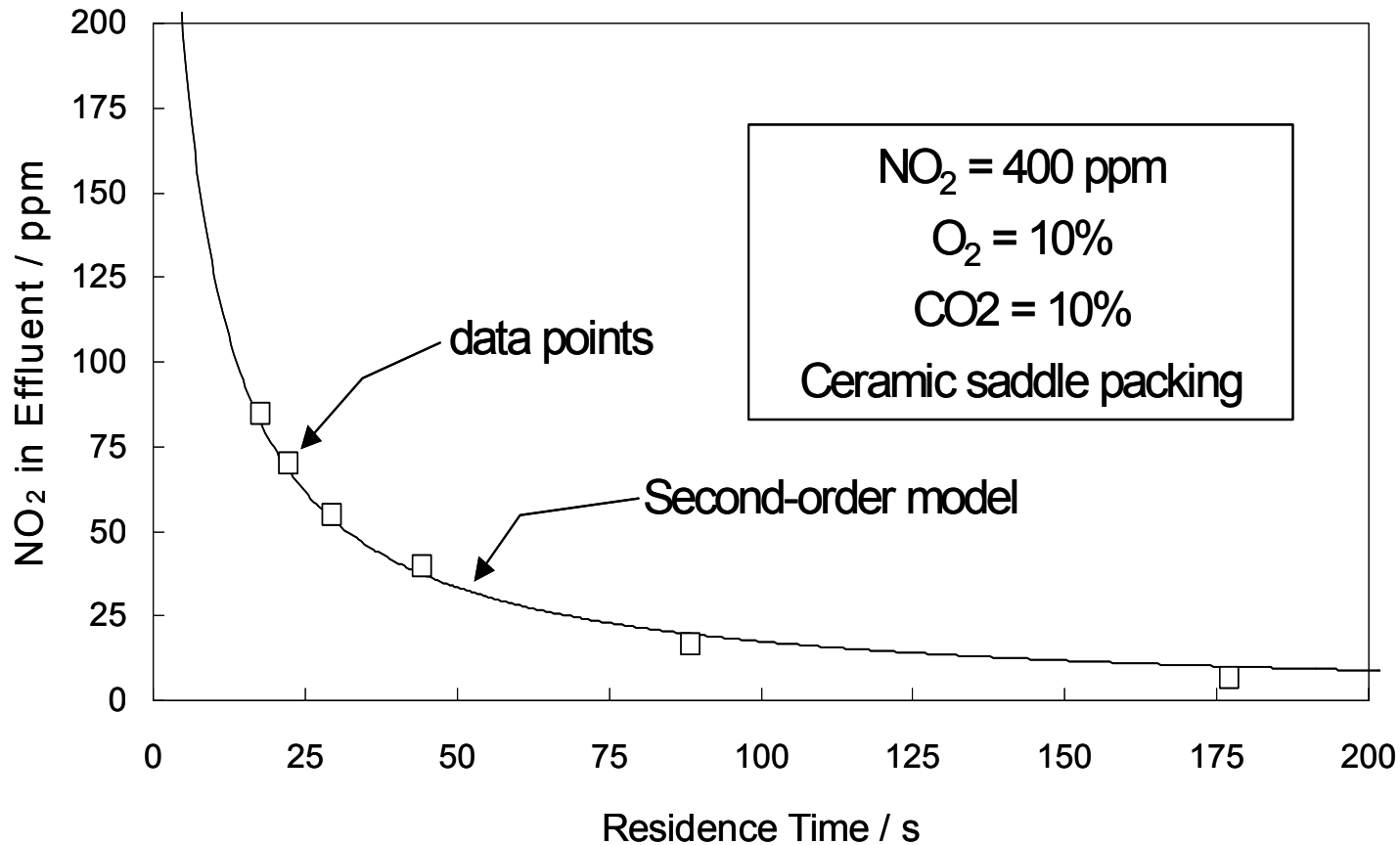
# NO Oxidation Tests

- **Pretreat catalyst at 350°C for 1 h in mixture of NO, CO<sub>2</sub>, and O<sub>2</sub>.**
- **Temp 350°C; 400 ppm NO, 10% CO<sub>2</sub>, 8% H<sub>2</sub>O, 10% O<sub>2</sub>, balance N<sub>2</sub>.**
- **Flow = 10,000 sccm/cc catalyst per hour.**
- **Measure conversion to NO<sub>2</sub>.**
- **Repeat measurements at 20°C intervals to 220°C.**

# TDA Oxidation Catalysts are Active at Low Temperatures



# NO<sub>2</sub> Removal is Slow at Low Concentrations



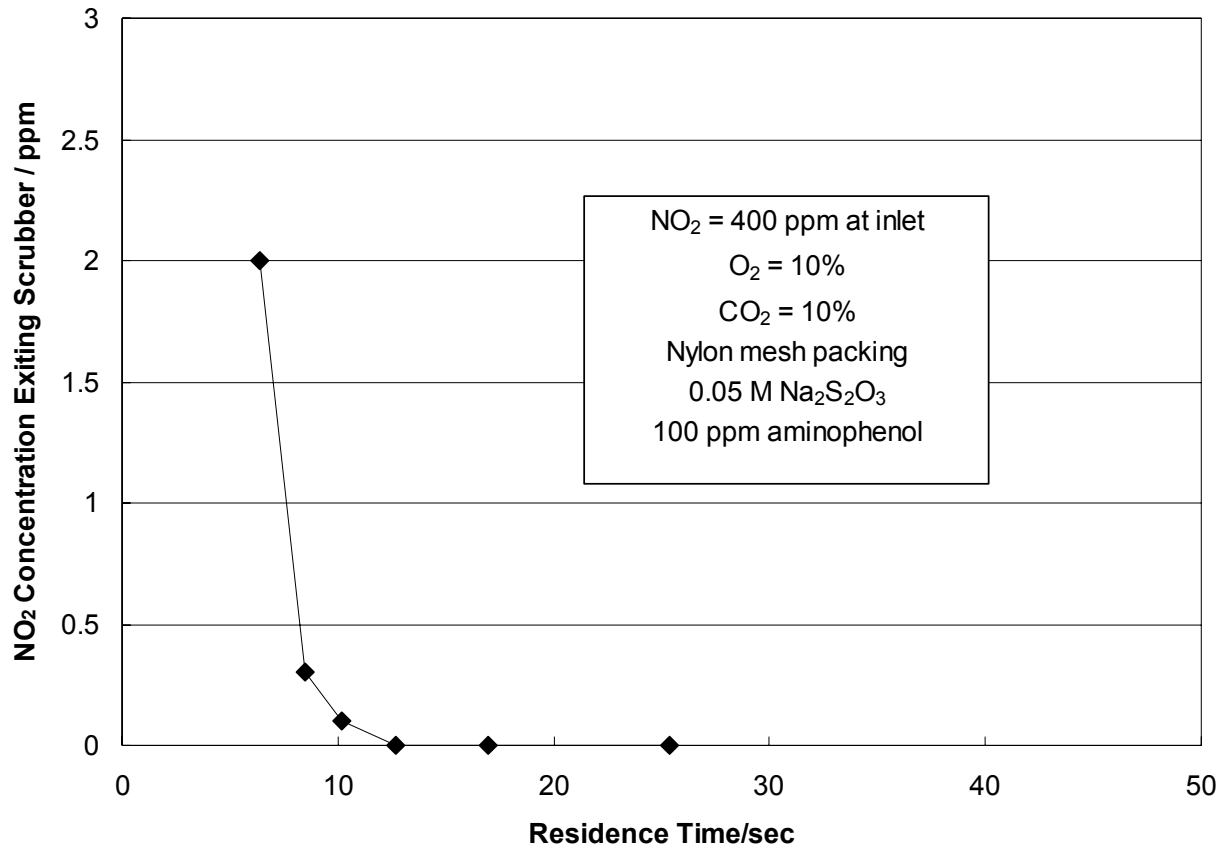
Scrubber using only water would require very long residence times.

# Alternative Scrubbing Approach

- **React NO<sub>2</sub> with an aqueous reducing agent in the presence of a catalyst\*.**
  - $R(NH_2) + NO_2 \rightarrow 1/2 N_2 + R(NH_2) (O_2)$
  - $2 R(NH_2) (O_2) + Na_2S_2O_3 \rightarrow R(NH_2) + Na_2S_2O_7.$
- **Reaction is very rapid and does not have second order dependency on NO<sub>2</sub>.**

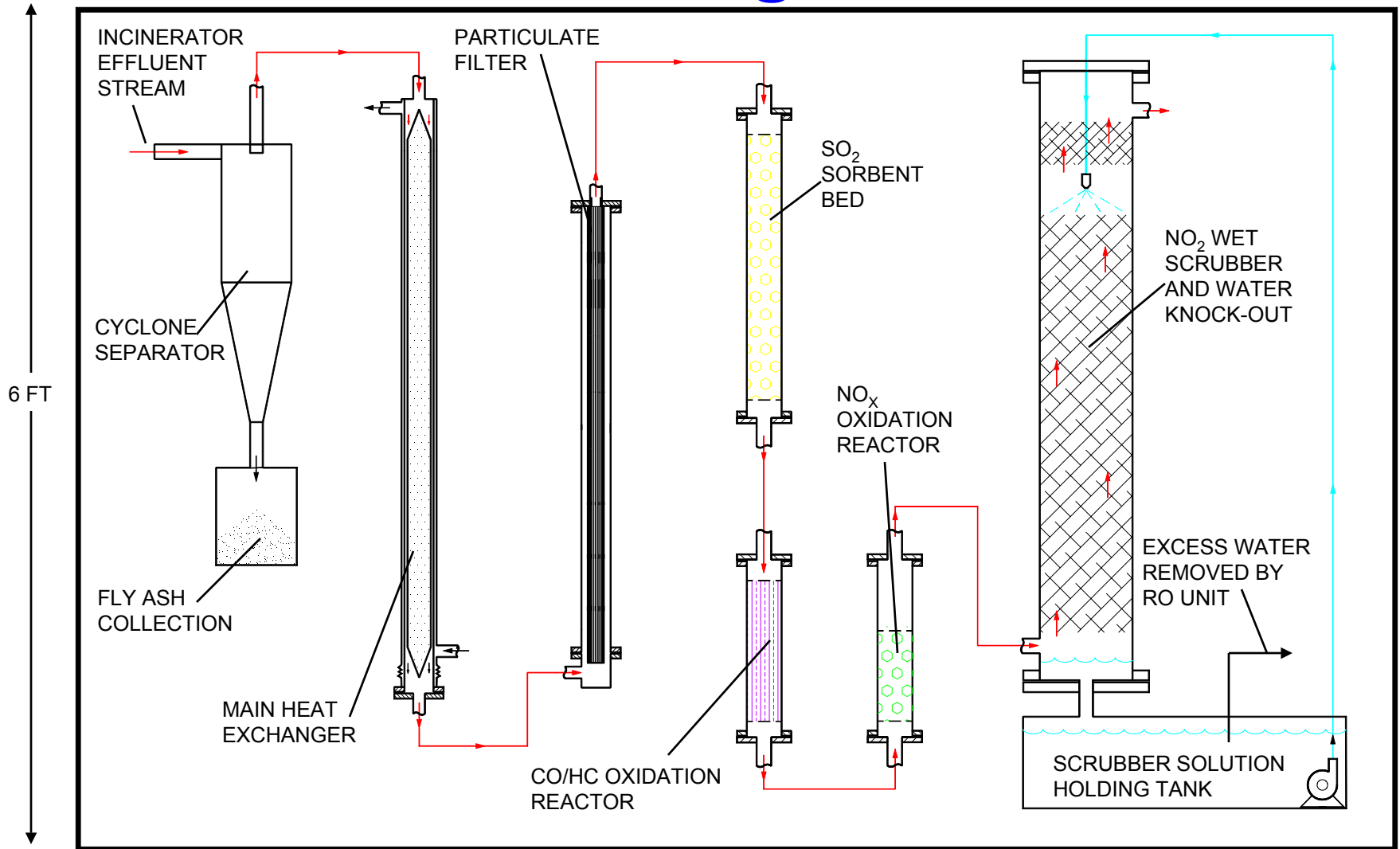
\* Senjo and Kobayashi, 1977

# Rapid Removal of NO<sub>2</sub>

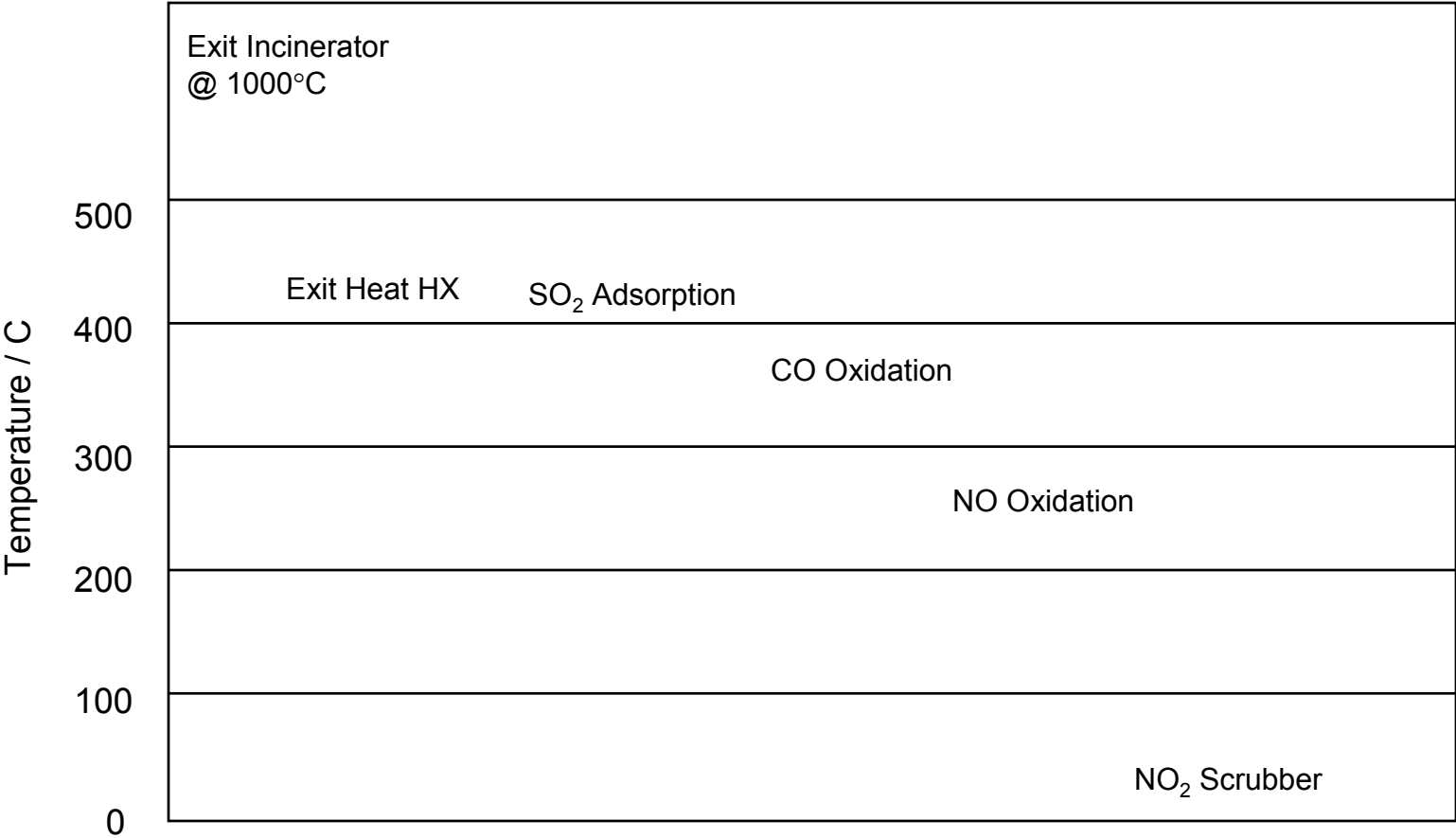


This solution is very effective for NO<sub>2</sub> even at very short residence times.

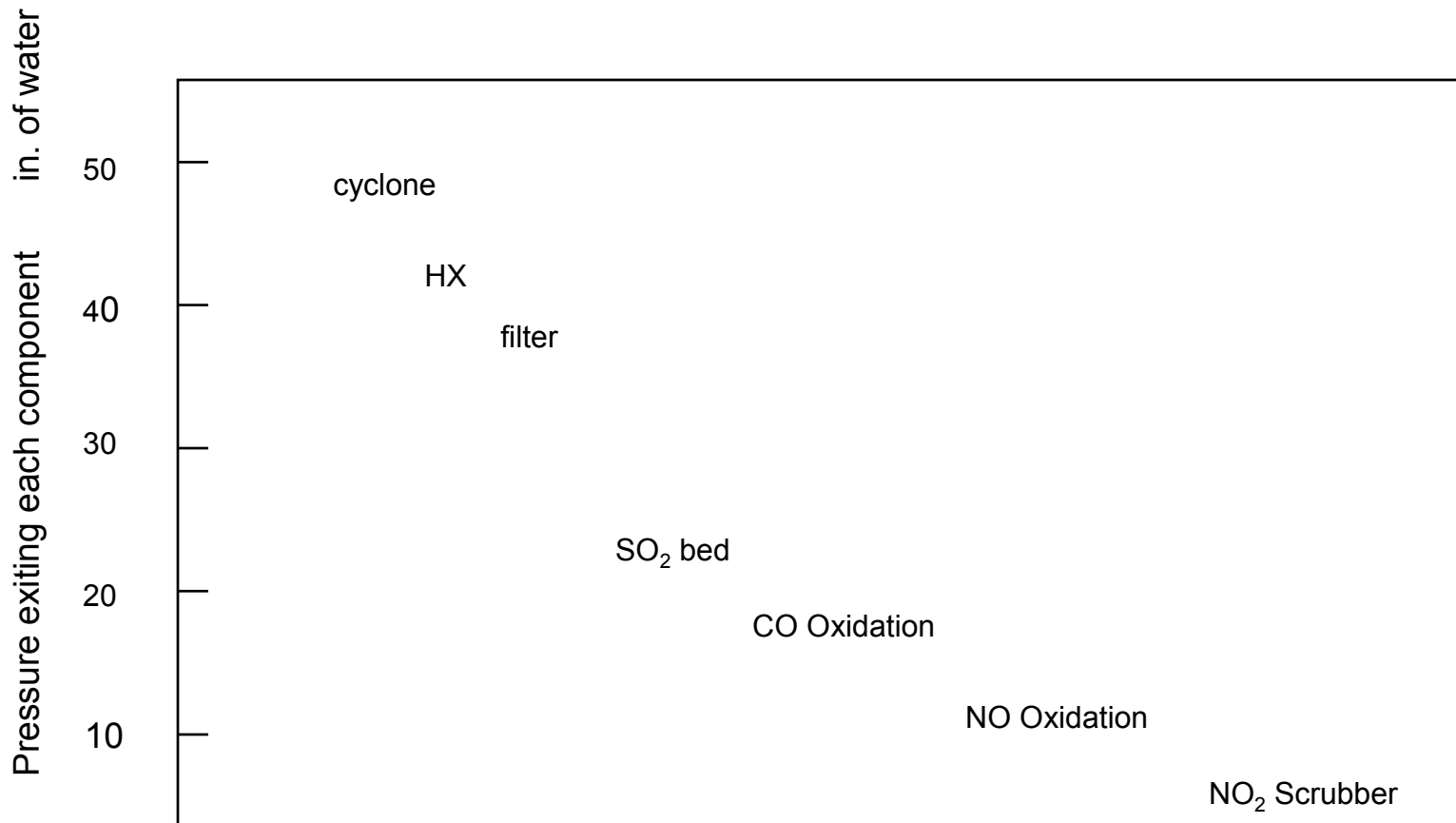
# Overall Design to Scale



# Design Temperature Profile



# Design Pressure Profile



# Acknowledgements

- **Funding provided by NASA SBIR program, contract NAS 9-99070.**
- **John Graf, NASA Johnson Space Center.**
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# Summary and Conclusions

- TDA has completed a preliminary design of a system to treat incinerator effluents.
- Particulate removed with a cyclone and a stainless steel filter.
- SO<sub>2</sub> controlled with a packed bed using TDA geode technology.
- NO<sub>x</sub> will be removed by oxidation and scrubbing using TDA oxidation catalyst.
- The overall system pressure drop is less than 2 psi.