Design and Construction of a Pilot Scale System to Remove Pollutants from Incinerator Effluents

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Overview

- **Phase II objective.**
- **Individual components.**
  - Hardware for cooling and particulate removal.
    - Cyclone.
    - Heat exchanger.
    - Particulate filter.
  - SO_2 adsorption in fixed bed reactor.
  - HC oxidation.
  - NO control by oxidation and wet scrubbing.
- **Process diagram.**
- **Description of system controls.**

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Phase II Objective

- **Design and construct a waste treatment system for use on the NASA Ames incinerator.**
- **Carry out laboratory tests to size components.**
- **Construct and test pilot scale components.**
- **Assemble and deliver the system.**

Incinerator Effluent Composition*

Component	Concentration	Kg/h
N_2	34%	4.22
O_2	6%	0.19
CO_2	10%	1.06
H_2O	49%	4.26
HC (CO)	1%	0.03
SO_2†	100 ppm	0.0005
NO_X	400 ppm	0.0005
Ash		0.001

Total design flow = 40 liters/min

*Fisher et al. 1998, SAE 981758; † Measured SO_2 < 1 ppm.

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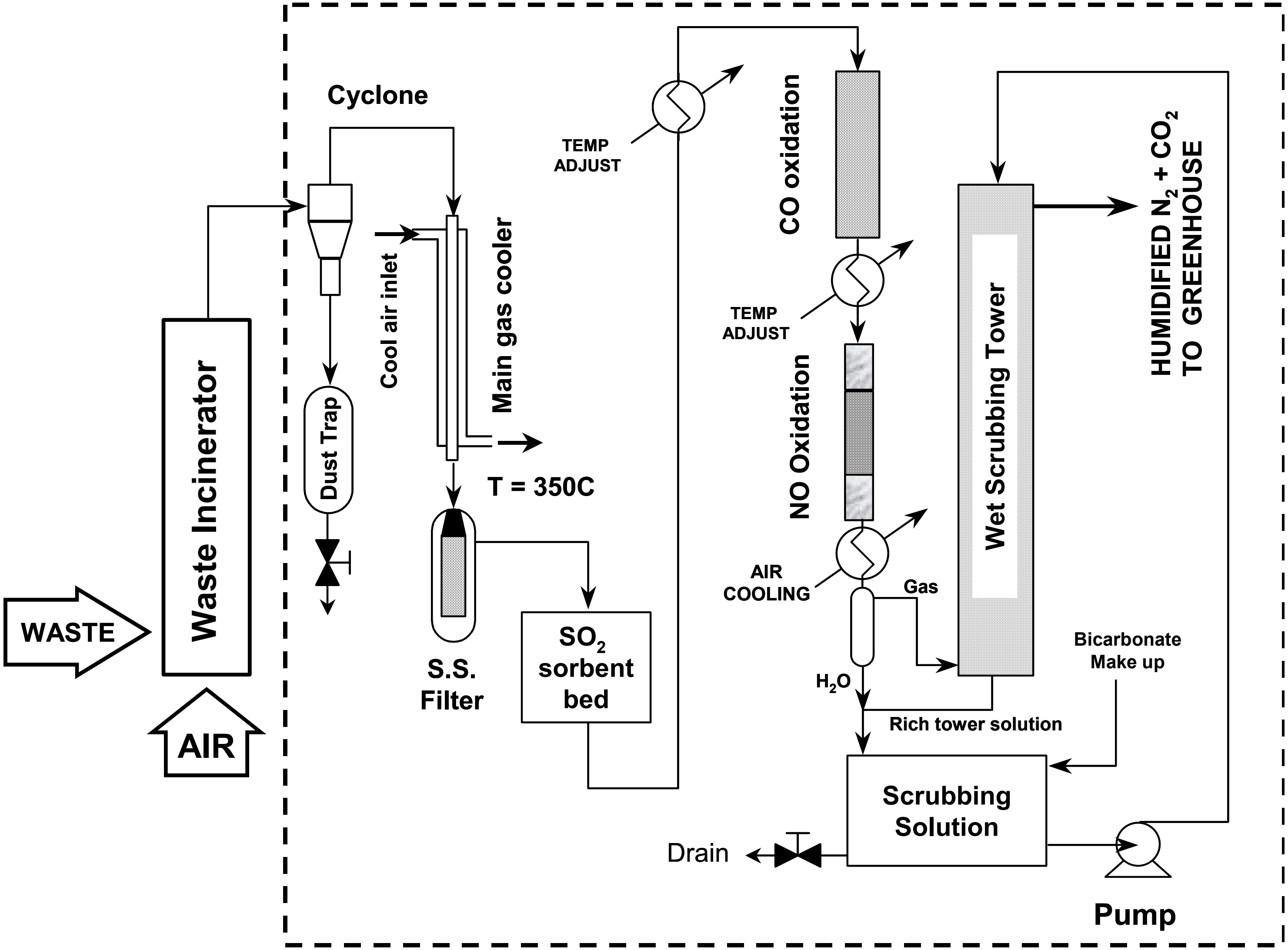
System Components

- **Components for process control.**
- **Hardware to remove particulate and cool effluent to 450°C.**
  - Cyclone.
  - Primary heat exchanger.
  - Filter.
- **Fixed bed SO_2 sorbent at 450°C.**
- **HC (CO) oxidation catalyst at 400°C.**
- **NO oxidation catalyst at 260°C.**
- **NO_2 scrubber and H_2O knockout at 25°C.**
- **Carbon bed to remove trace levels of NO.**

TDA Waste Treatment System



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NO_X Control

- **NO SMAC = 6.1 mg/m^3 or 4.5 ppm.**
- **NO_2 SMAC = 0.94 mg/$_3$ or 0.46 ppm.**
- **Current technologies:**
  - Selective Reduction (catalytic and non catalytic).
    - Reducing agent must react with NO instead of O_2.
    - $3\ NO + 2\ NH_3 \rightarrow 5/2\ N_2 + 3\ H_2O$.
  - Combustion modification (reducing temperature) - only moderately effective.
  - To date, no catalyst has been identified that is active for the direct decomposition of NO into N_2 and O_2.

Problems with Selective Reduction for NO_x 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_3 injection to changing NO concentrations.**
- **Handling ammonia can be dangerous and requires pressurized tank.**

NO_x Removal by Oxidation and Scrubbing

- Take advantage of excess oxygen in effluent stream to catalytically oxidize NO (90% of NO_X) to NO_2.
- Use a wet scrubber to remove NO_2 from the waste stream (NO has a low solubility in water and therefore cannot be scrubbed).

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Chemical Reactions

- **Oxidation**
  - $NO + 1/2\ O_2 \rightarrow NO_2$
  - Occurs rapidly on catalyst, slowly in air.
  - Must be done at temperatures below 300°C.
- **Adsorption and neutralization of NO_2**
  - $2\ NO_2 + H_2O \rightarrow HNO_3 + HNO_2$
  - Strongly favored by thermodynamics at low concentrations.
  - $HNO_3 + HNO_2 + 2\ NaOH \rightarrow NaNO_3 + NaNO_2 + 2H_2O$.

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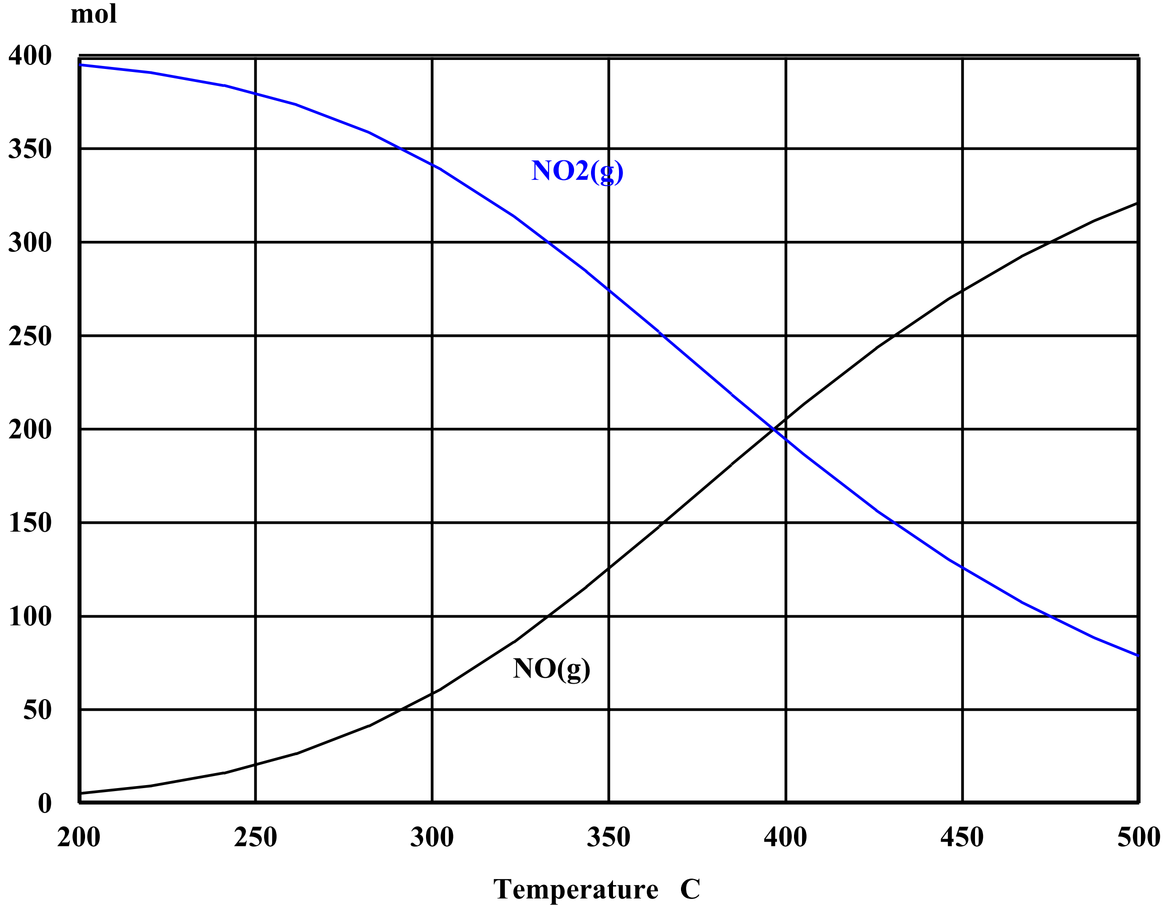
Thermodynamics require NO Oxidation at Low Temperature



Advantages of NO_x 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_3.
- Does not require use of toxic compound in pressurized tank.
- No potential for exposing crew to ammonia.

System for NO_X Control

- **Tests to optimize NO oxidation catalysts.**
  - Identify optimum temperature.
  - Effects of water and oxygen.
- **Tests to optimize NO_2 scrubber efficiency.**
  - Tests with water.
  - Tests with aqueous reducing agent.
- **Calculations to determine optimum configuration.**

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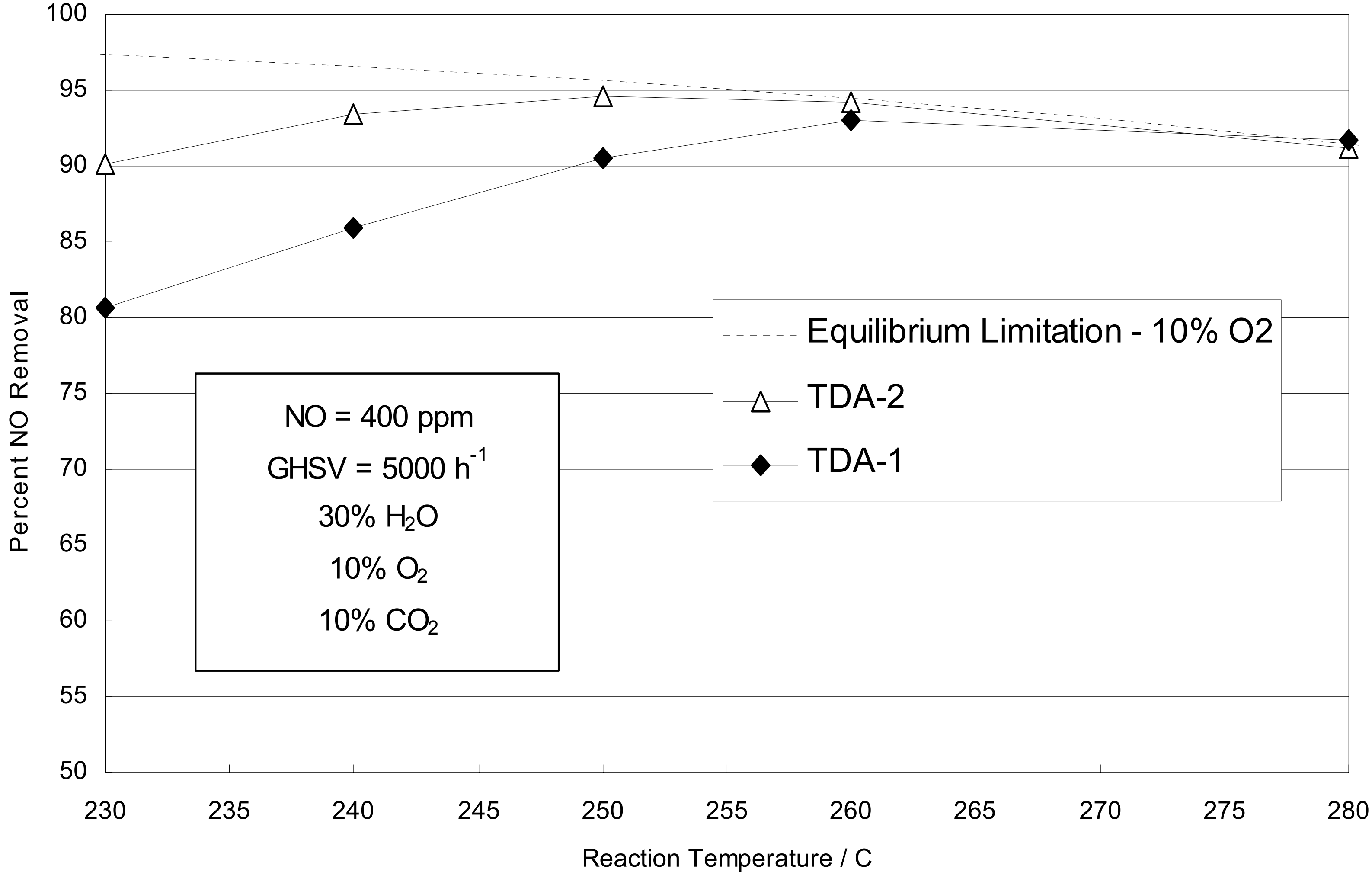
Operation at 250°C Provides Best Activity



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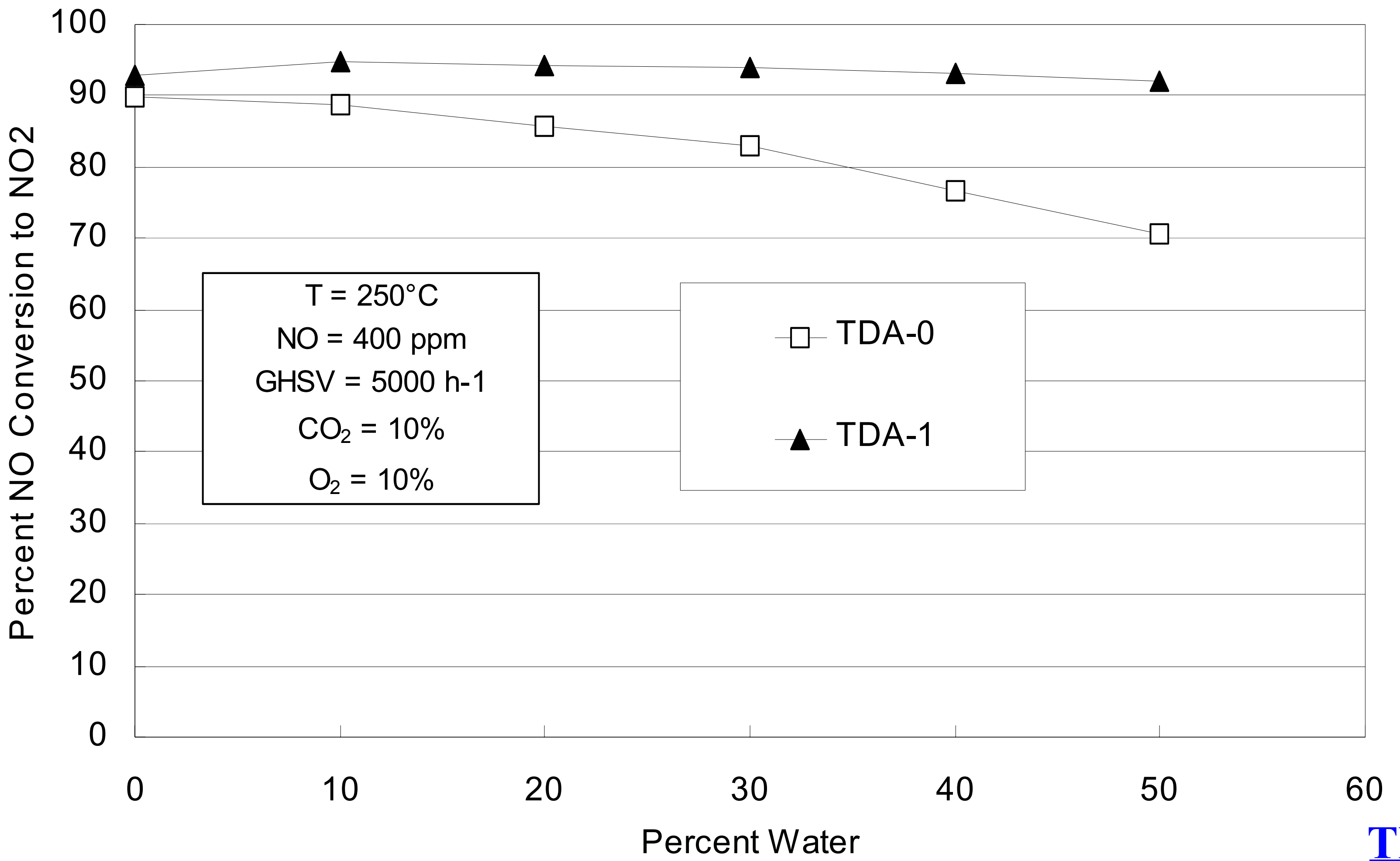
Catalyst is Not Affected by Water



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Catalyst Bed Design

- **The oxidation reactor will be 4-in diameter x 2.5-ft in length; GHSV = 2500 h^{-1}.**
- **Contain ¼-in catalyst pellets.**
- **Temperature profile will be adjusted to maximize the conversion to NO_2.**
  - Part of the bed at 260°C - 95% reached rapidly.
  - End of the bed at 230°C - 98% at equilibrium.
- **Pressure drop will be about 6-in H_2O.**

Removal of NO_2 from the Effluent

- Our original approach was to scrub NO_2 in water, forming HNO_2 and HNO_3.
- Neutralization with NaOH produces $NaNO_3$ and $NaNO_2$.
- Scrubber also serves as water knock-out.
- With 50% water and 400 ppm NO, concentrations of $NaNO_2$ and $NaNO_3$ are 1518 and 1870 ppm respectively.
- Could be used as plant nutrients.

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Kinetics of NO_2 Adsorption in Water

$$NO_{2\,(g)} + NO_{2(g)} \rightarrow N_2O_{4(g)}$$

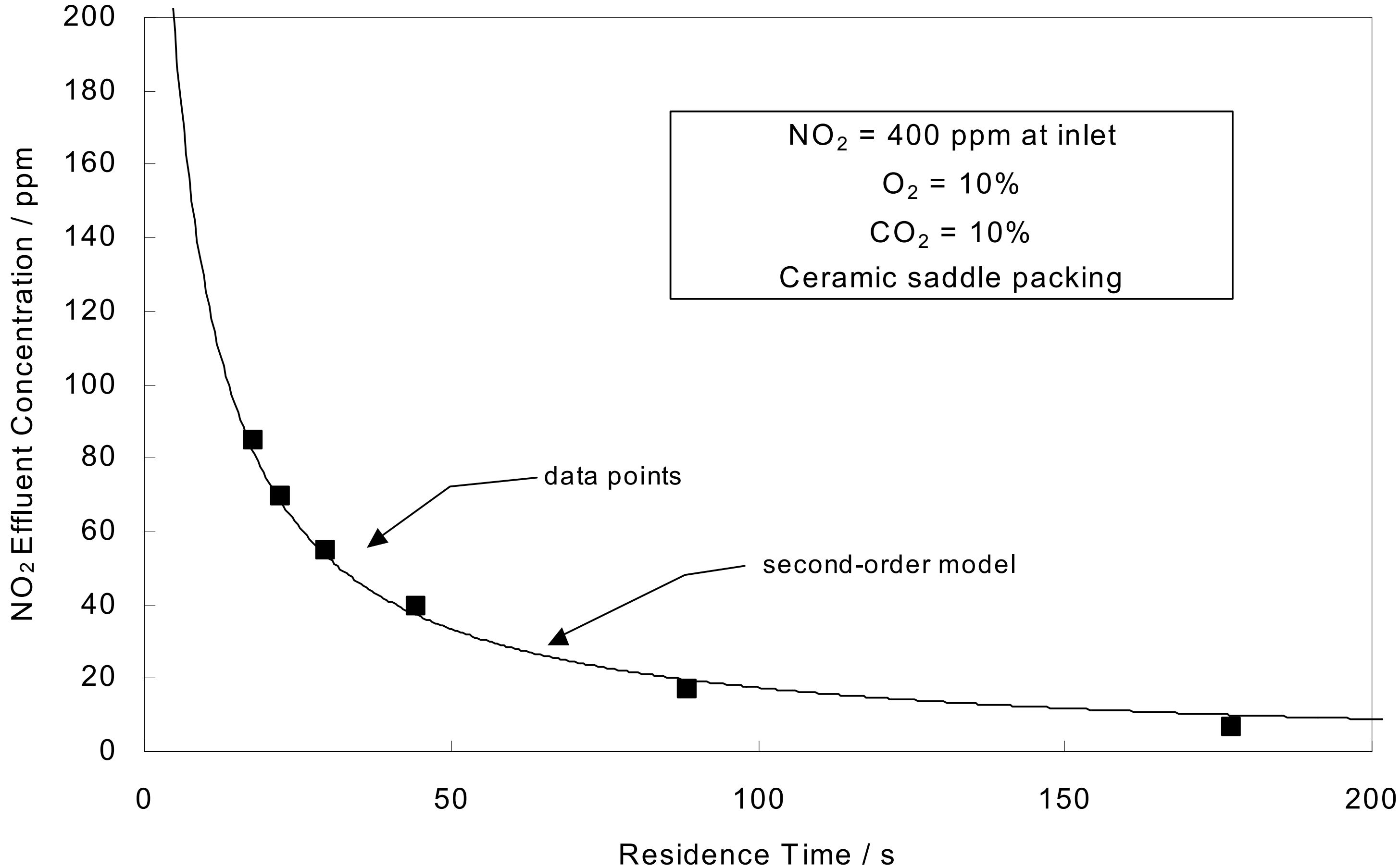
$$N_2O_{4(g)} \rightarrow N_2O_{4(l)}$$

$$N_2O_{4(l)} + H_2O \rightarrow HNO_3 + HNO_2$$

$$\text{Rate of Absorption} = k\,P^2_{(NO2)}$$

Rate is fast at high concentrations but very slow at low concentrations.

NO_2 Removal is Slow at Low Concentrations



Residence time of 700 seconds required to meet SMAC of 0.46 ppm.

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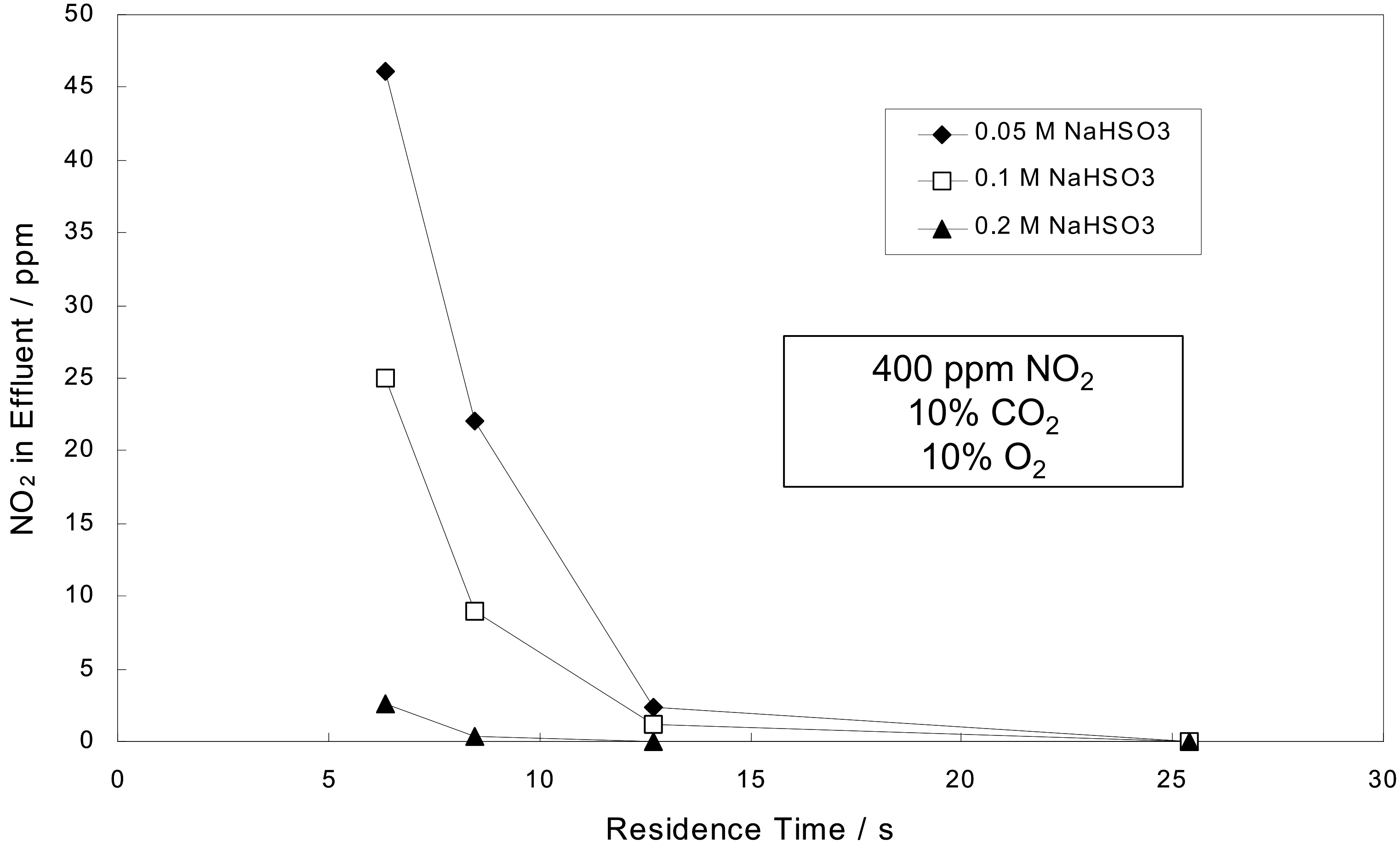
Alternative Scrubbing Approach

- **React NO_2 with an aqueous reducing agent in the presence of a catalyst*.**
  - $R(NH_2) + NO_2 \rightarrow 1/2\ N_2 + R(NH_2\text{-}O_2)$
  - $R(NH_2\text{-}O_2) + 2\ NaHSO_3 \rightarrow R(NH_2) + 2NaHSO_4$.
- **Reaction is very rapid and does not have second order dependency on NO_2.**

* Senjo and Kobayashi, 1977

Reducing Solution Rapidly Removes NO_2



This solution is very effective for NO_2 even at very short residence times.

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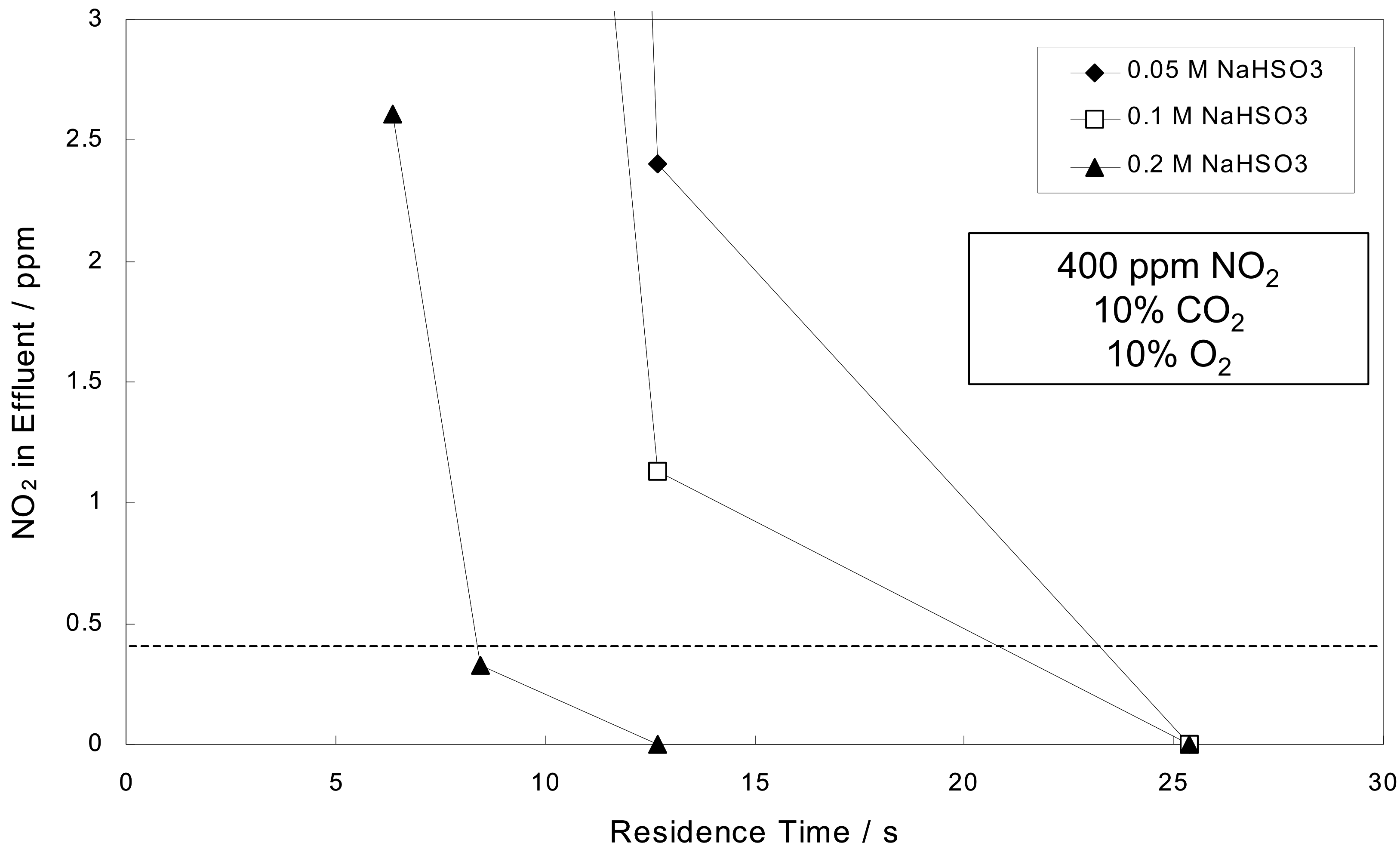
NO_2 SMAC Met in Eight Seconds



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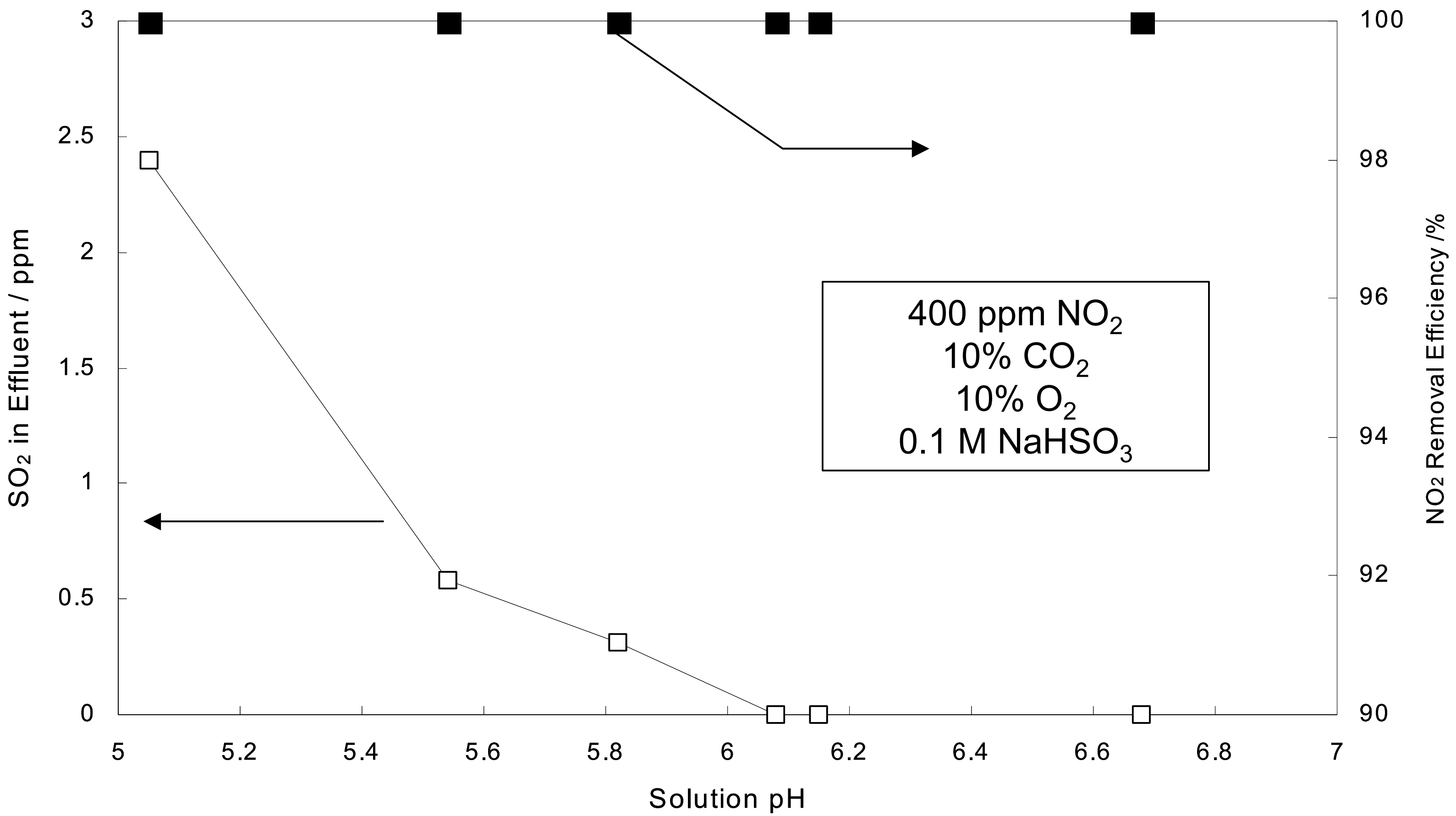
Bisulfite Solution Does Not Produce SO_2 at Neutral pH.



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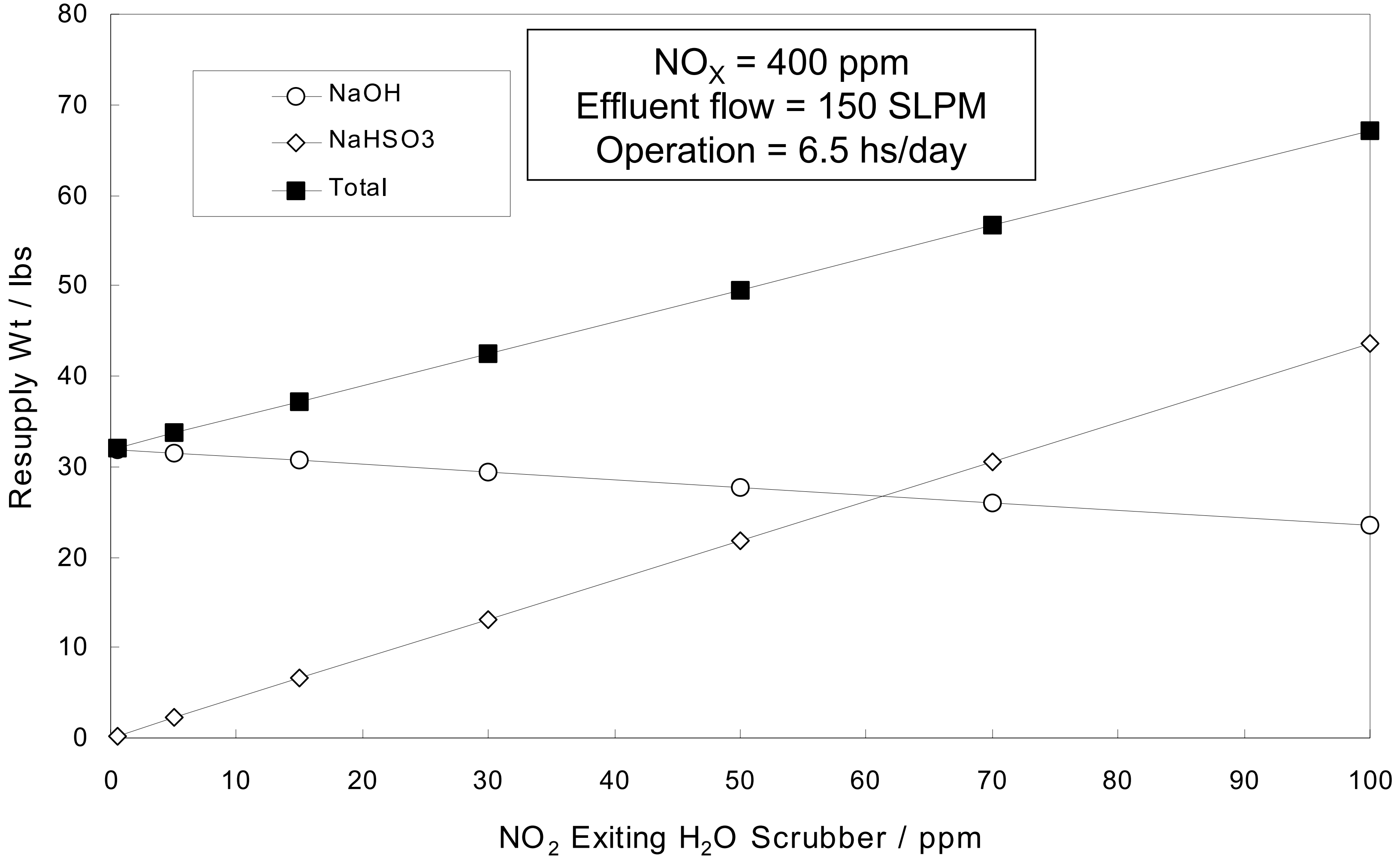
Tradeoffs for Each Scrubber

- **Single scrubber with water.**
  - + Reagent weight of 31 lbs per year (NaOH).
  - + Neutralized liquid can be used for plants.
  - - Column size:15-in OD x 21-ft;
  - - Weight = over 400 lbs.
- **Single scrubber with bisulfite.**
  - + Column size is 6-in x 3.3 ft.
  - + Weight less than 10 lbs.
  - - Reagent weight of 150 lbs per year.
  - - Liquid effluent must be treated by RO.

Use of Two Scrubbers in Series

- Assume water scrubber is first, followed by bisulfite solution.
- Assume various concentrations of NO_2 in the effluent of the water scrubber.
- Assume balance of NO_2 is removed in the reducing scrubber.
- Calculate size and weight of the water scrubber along with reagent weights for both units.

Reagent Weight Increases with NO_2 Levels Exiting Water Scrubber



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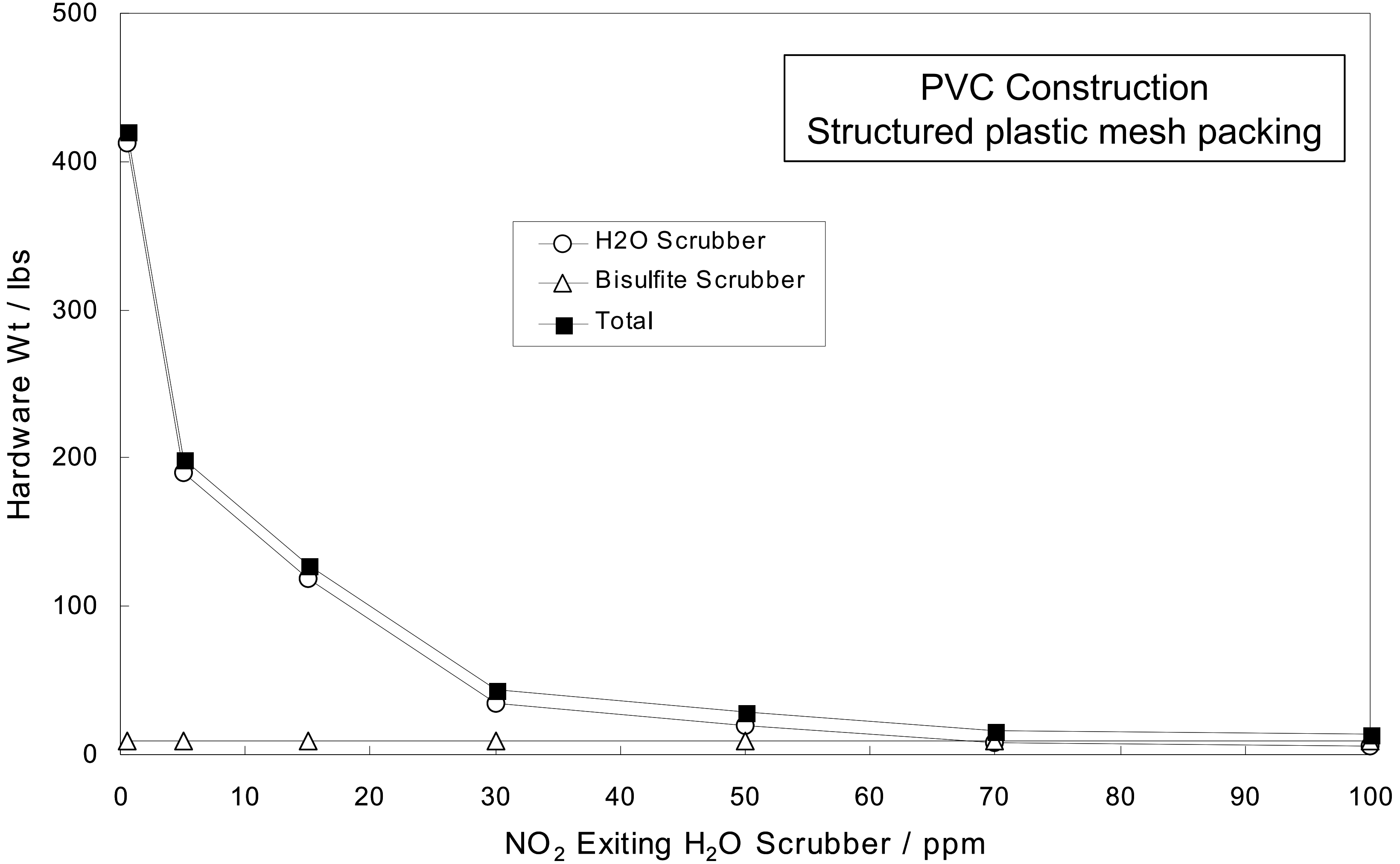
Water Scrubber Dominates Hardware Weight



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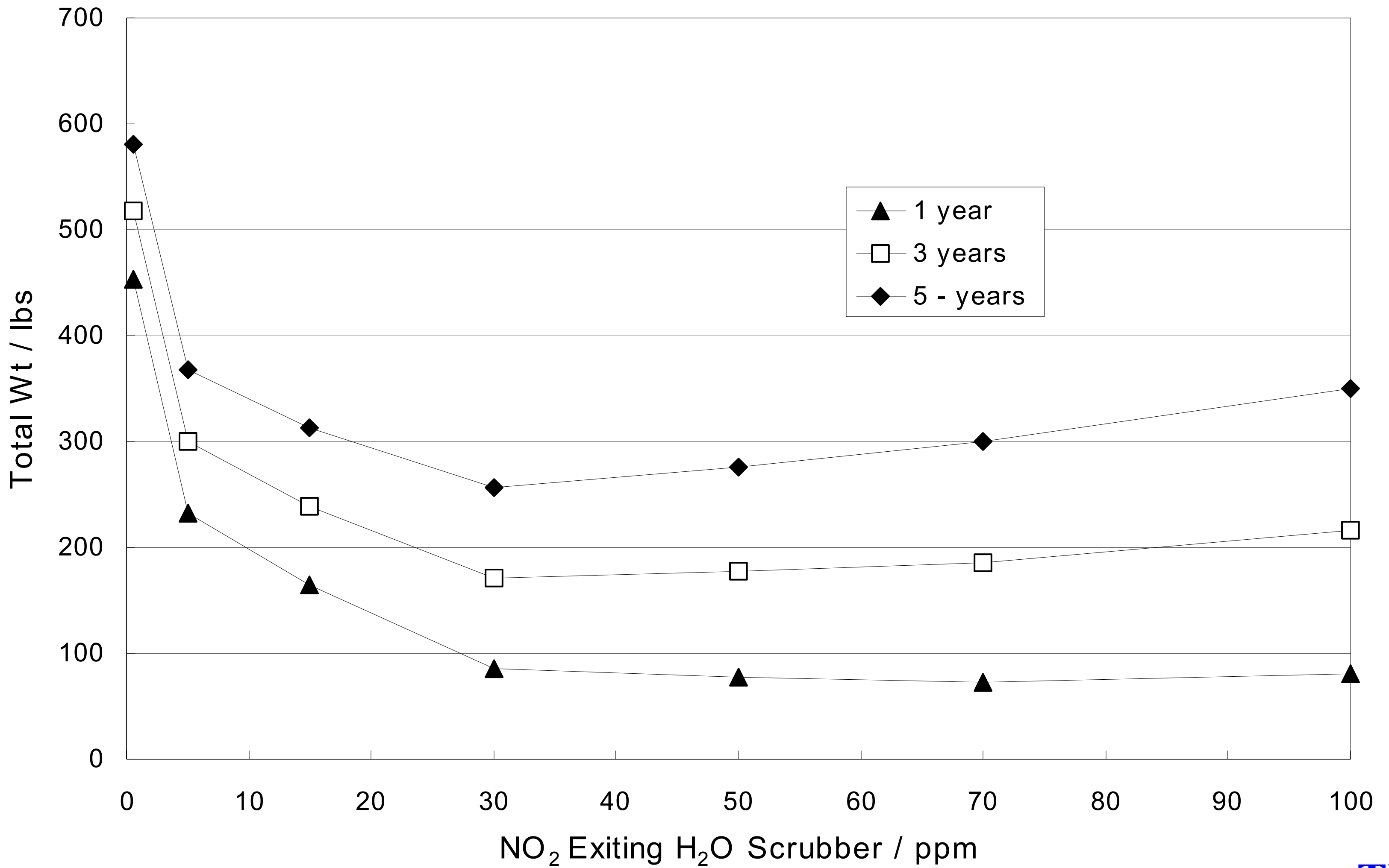
Optimum at 30 to 70 ppm NO_2 Exiting Water Scrubber



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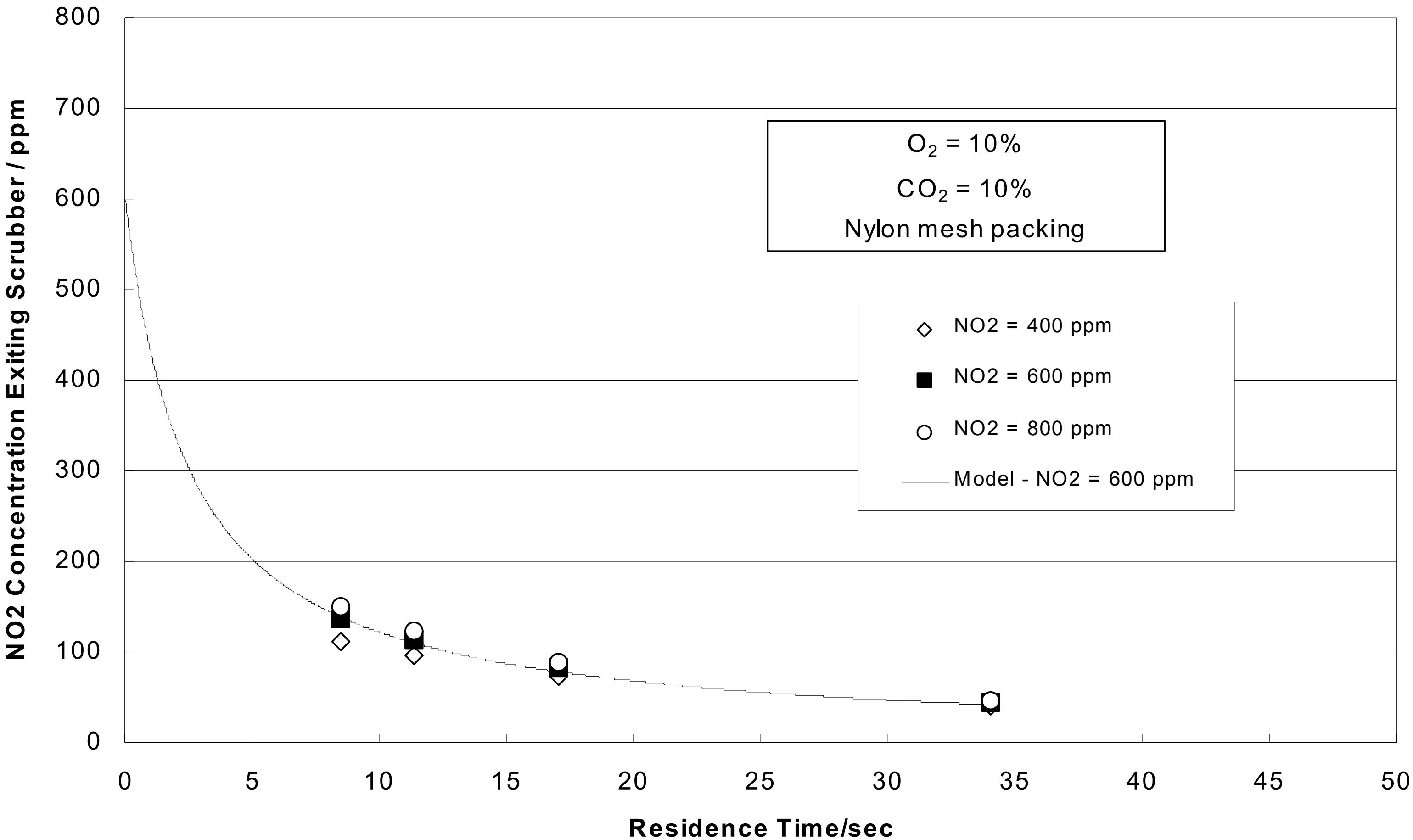
Water Scrubber Equalizes Variable NO_2 Feed Concentrations



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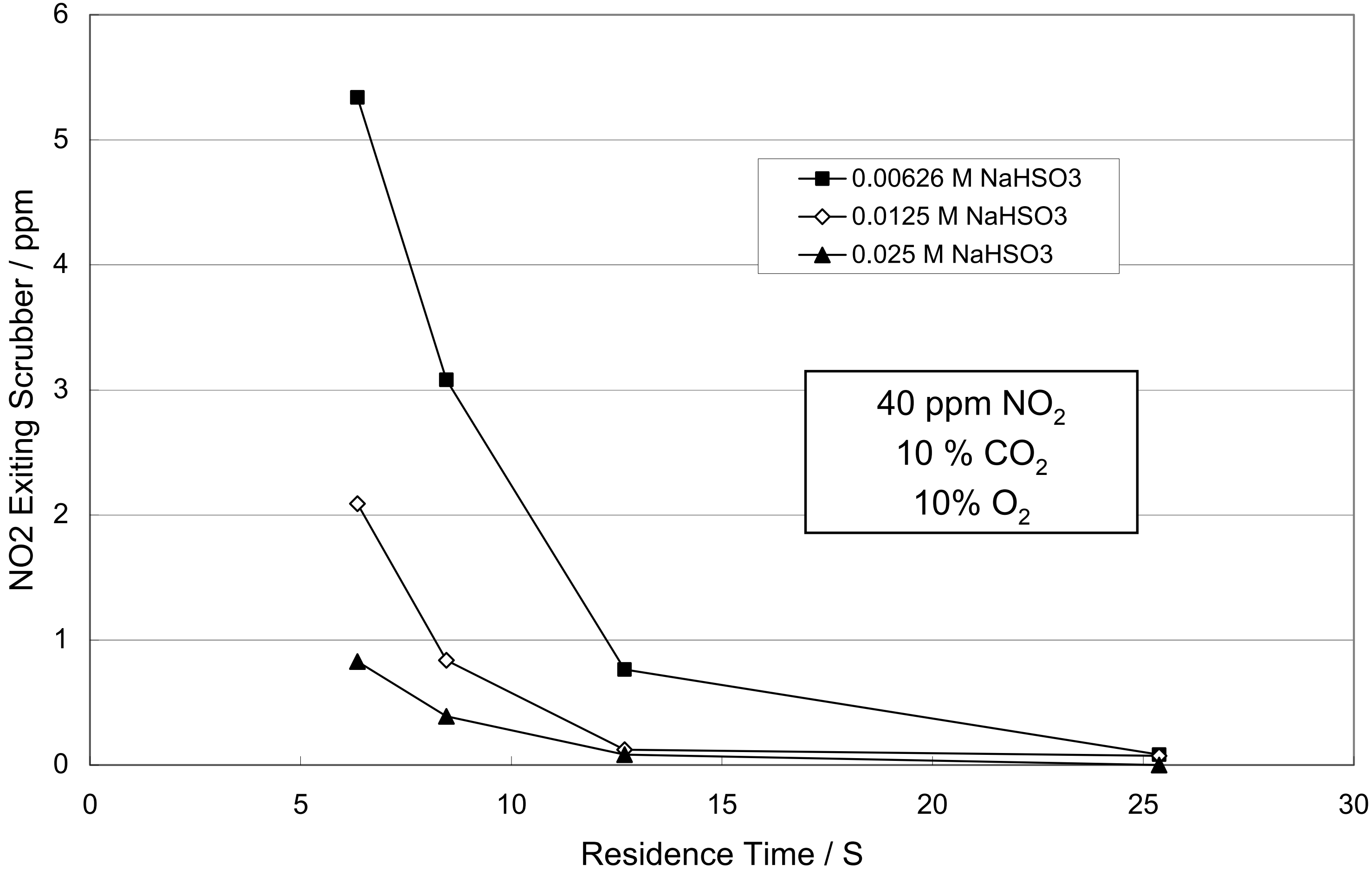
Less Reagent Required in Second Scrubber at Low NO_2 Concentrations



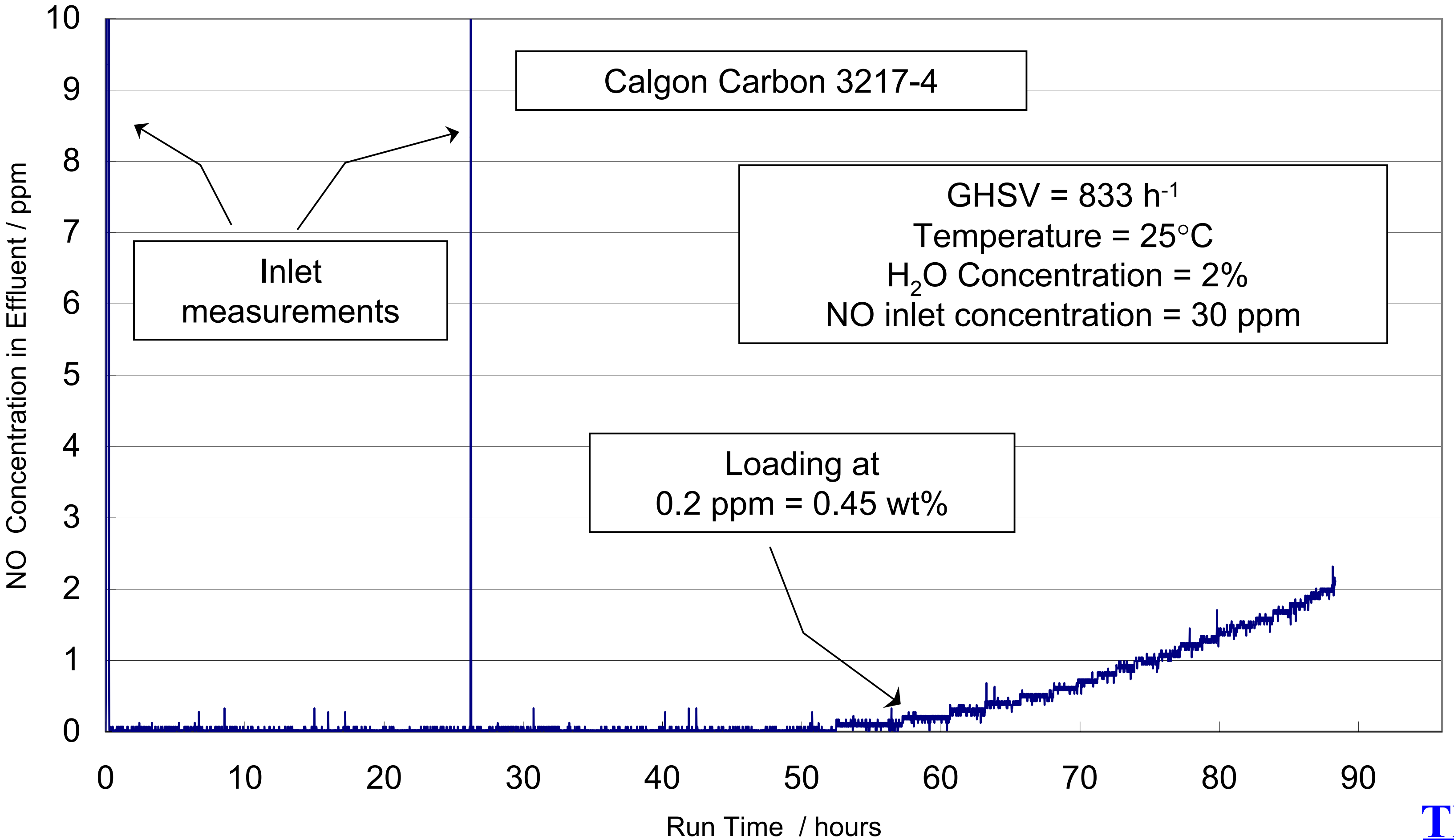
Summary of NO_2 Scrubber

- Water scrubber sized to allow about 50 ppm NO_2 in effluent.
- It will be 8-in OD x 4 ft in height and will weigh about 10 lbs.
- Bisulfite scrubber will be 6-in diameter by 3.3 ft in height.
- NO_2 levels in the effluent will be less than 0.1 ppm (SMAC = 0.46 ppm).

Carbon Bed

- May be needed to absorb low levels of NO.
- At 97.5% conversion of NO to NO_2, about 0.6 lbs of NO would be generated in one year.
- Amount of carbon will depend on loading.
- TDA is currently evaluating samples prepared by Calgon.

Carbon Bed to Remove Trace Levels of NO



Full Scale Apparatus

Full Scale Apparatus

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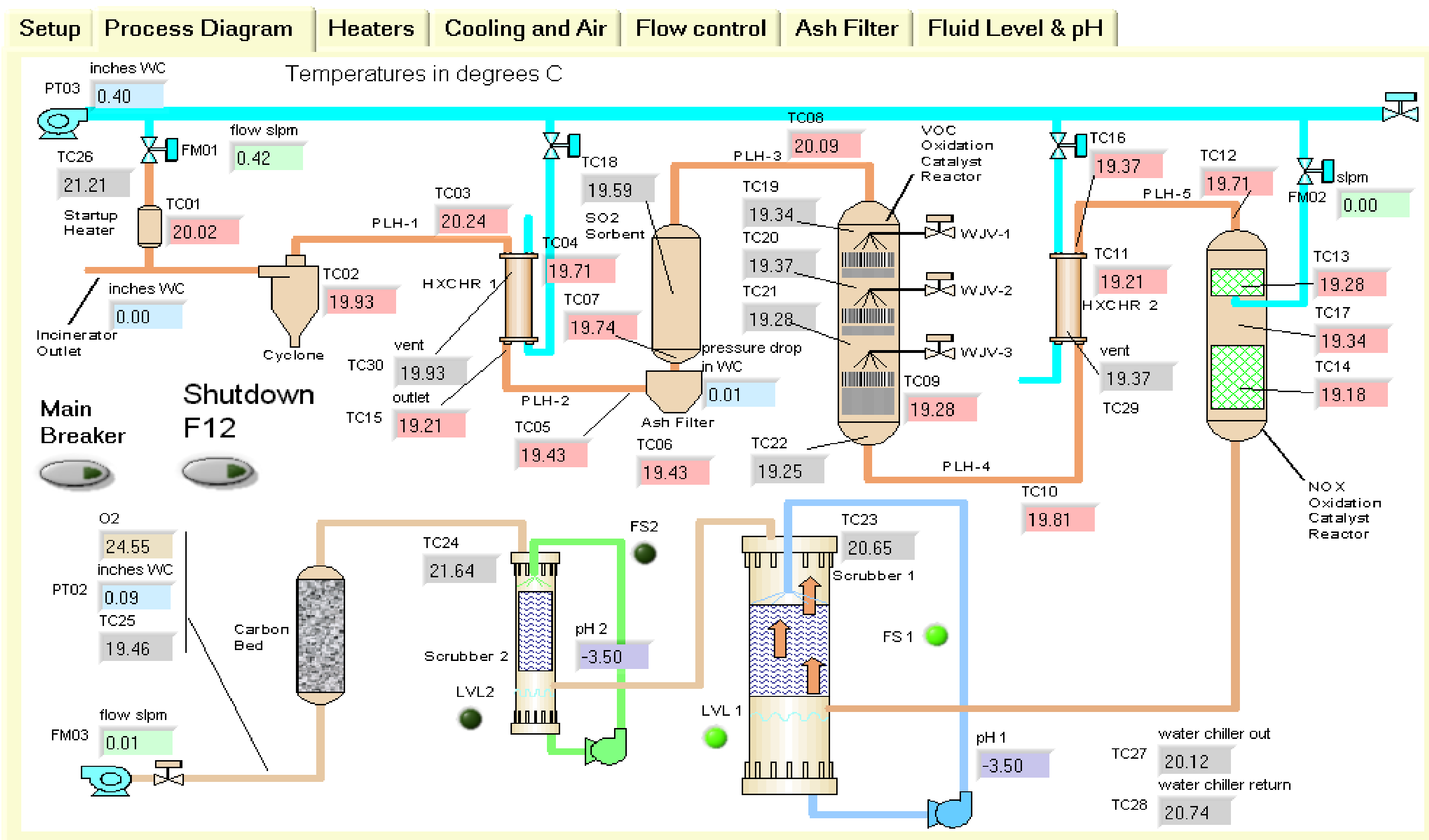
Labview Software used for System Control



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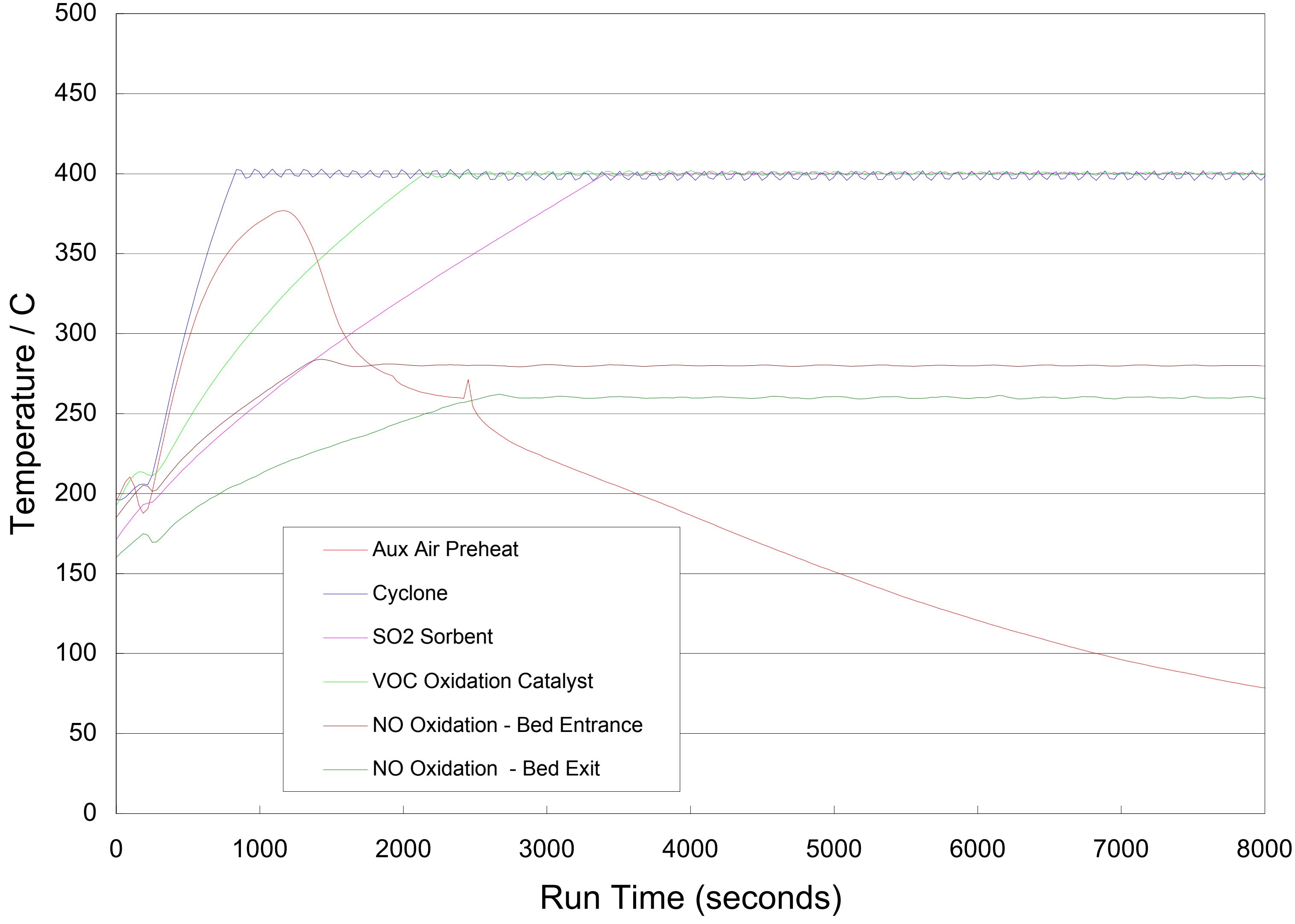
Initial Checkout Shows Good Temperature Control



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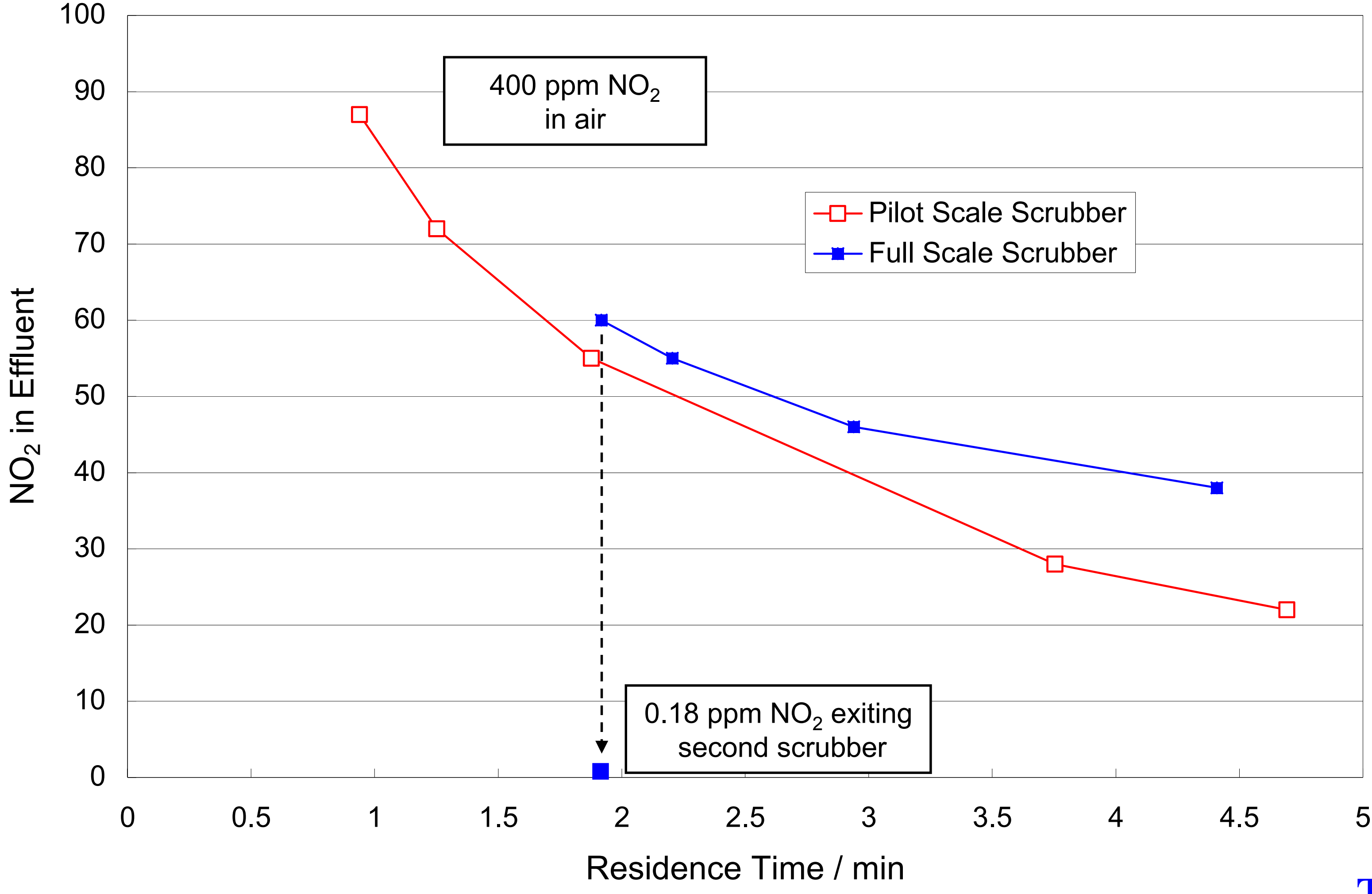
Scrubbers are Effective for NO_2 Removal



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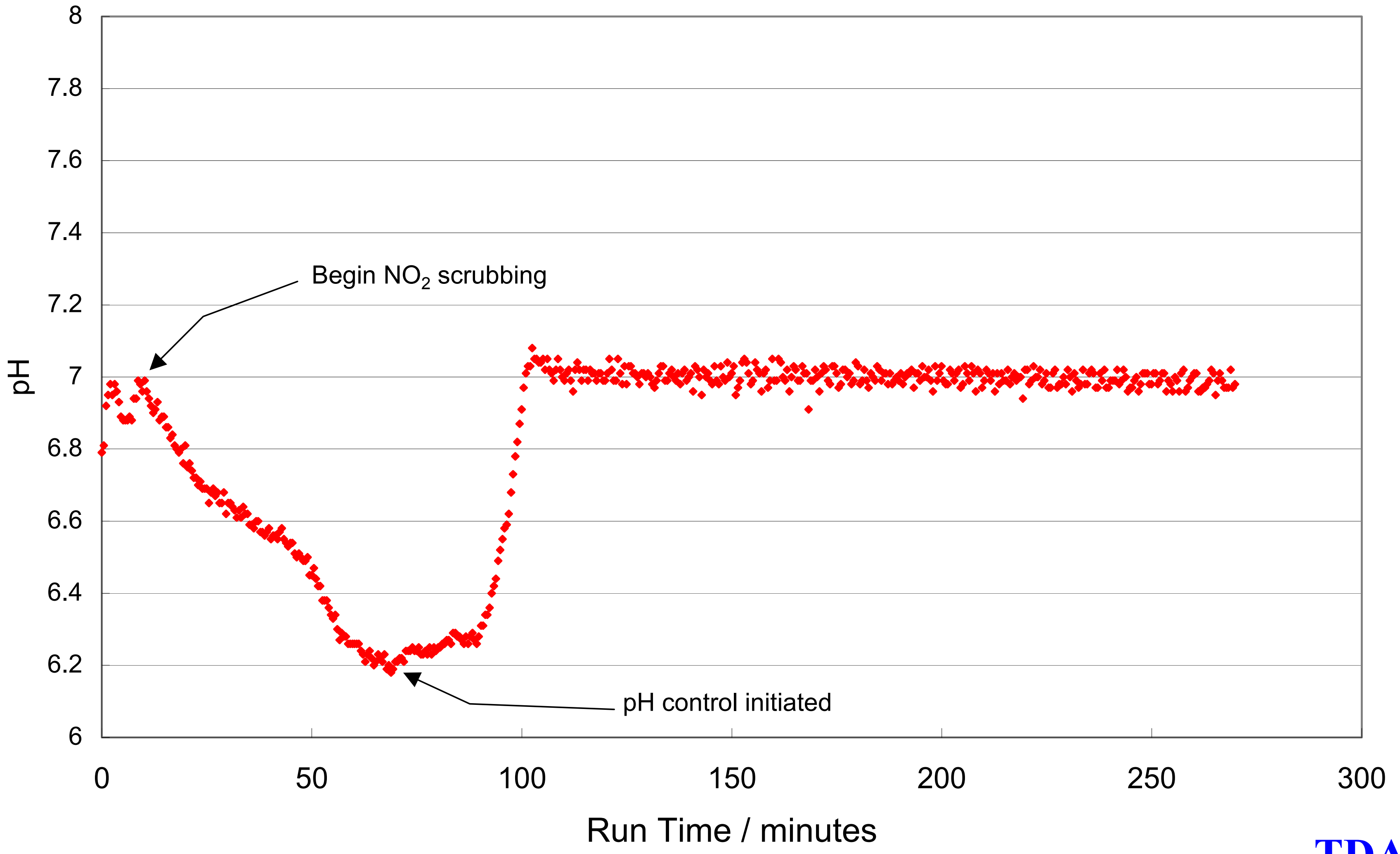
System Provides Good Control of pH in Water Scrubber



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Summary and Conclusions

- TDA has designed and constructed a system to treat incinerator effluents.
- NO_X will be removed by oxidation and scrubbing using TDA oxidation catalyst.
- NO_2 scrubbing is accomplished by two scrubbers in series.
- Initial check out of the system shows that it is performing as anticipated.

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