# Active photocatalytic air cleaners

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Berkeley, June 29th 2007

# Indoor air cleaning technologies

**UV photocatalytic oxidation (UVPCO)**

Outdoor or recirculated indoor air with VOCs → UVPCO → "Clean" air with lower VOCs

**In-duct systems**

**Standalone home air cleaners**

# Goals of our study:
# performance evaluation of UVPCO

## Main questions:

Can we eliminate airborne pollutants from indoor air?

Are air cleaning technologies energy-efficient and safe?

## How do we define performance?

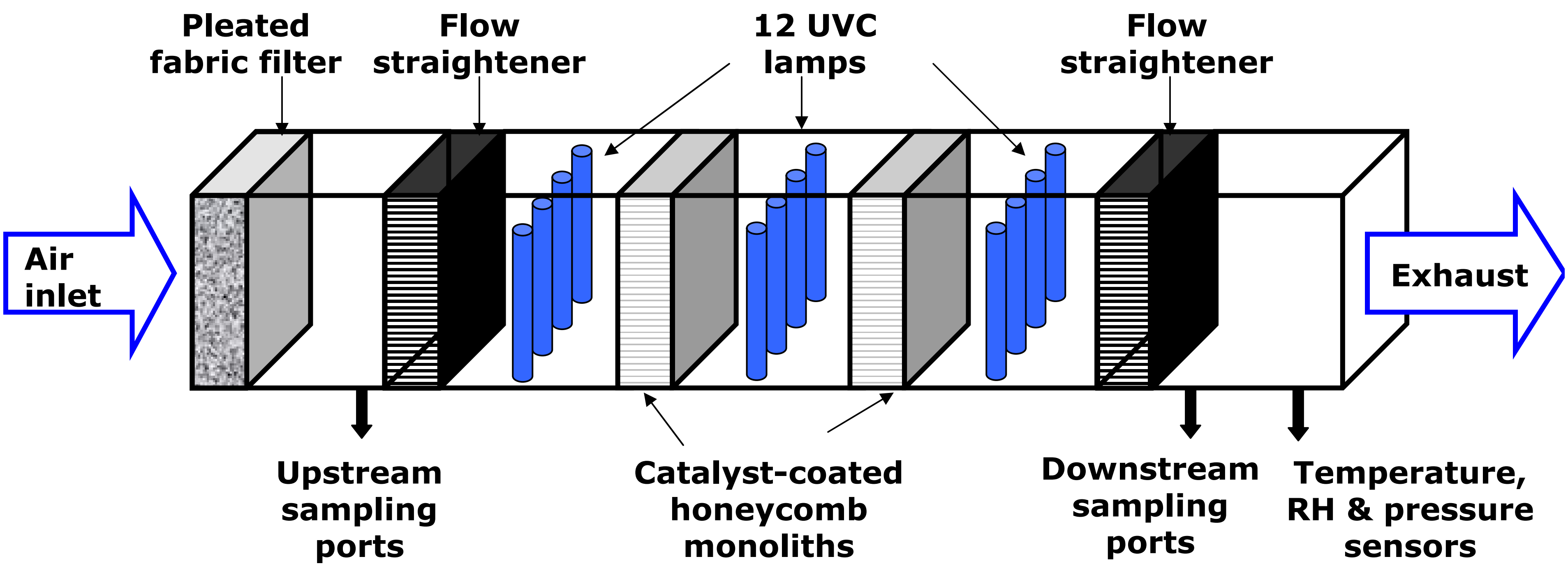
Removal efficiency of target pollutants

Formation of undesired oxidation byproducts

Catalyst inactivation

# UVPCO reactor schematics

**In-duct, single pass, plug-flow reactor**




| | |
|---|---|
| UV irradiation: 254 nm, 5 Watts/lamp | Face velocity: 0.5–1.8 m/s |
| Flow range: 150-600 $m^3/h$ | Residence time: 0.03-0.1 s |
| Max pressure drop: 35 Pa | Temperature: 20-25 $^oC$ |
| Total VOC concentration: 54-780 ppb | Relative humidity: 42-65 % |

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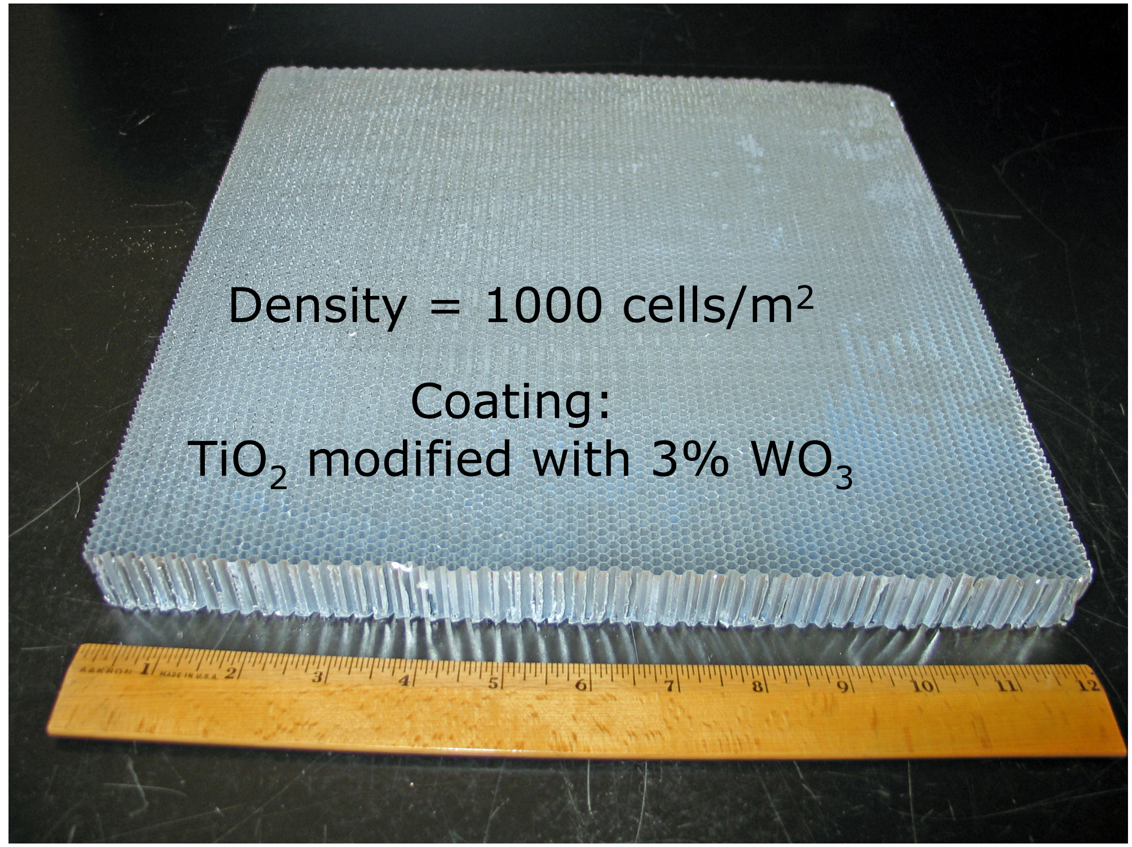
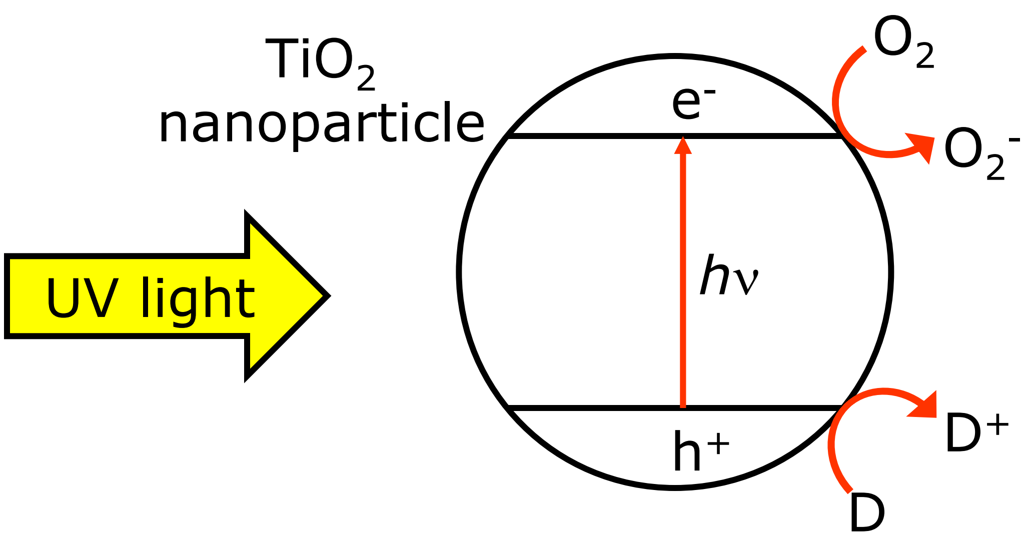
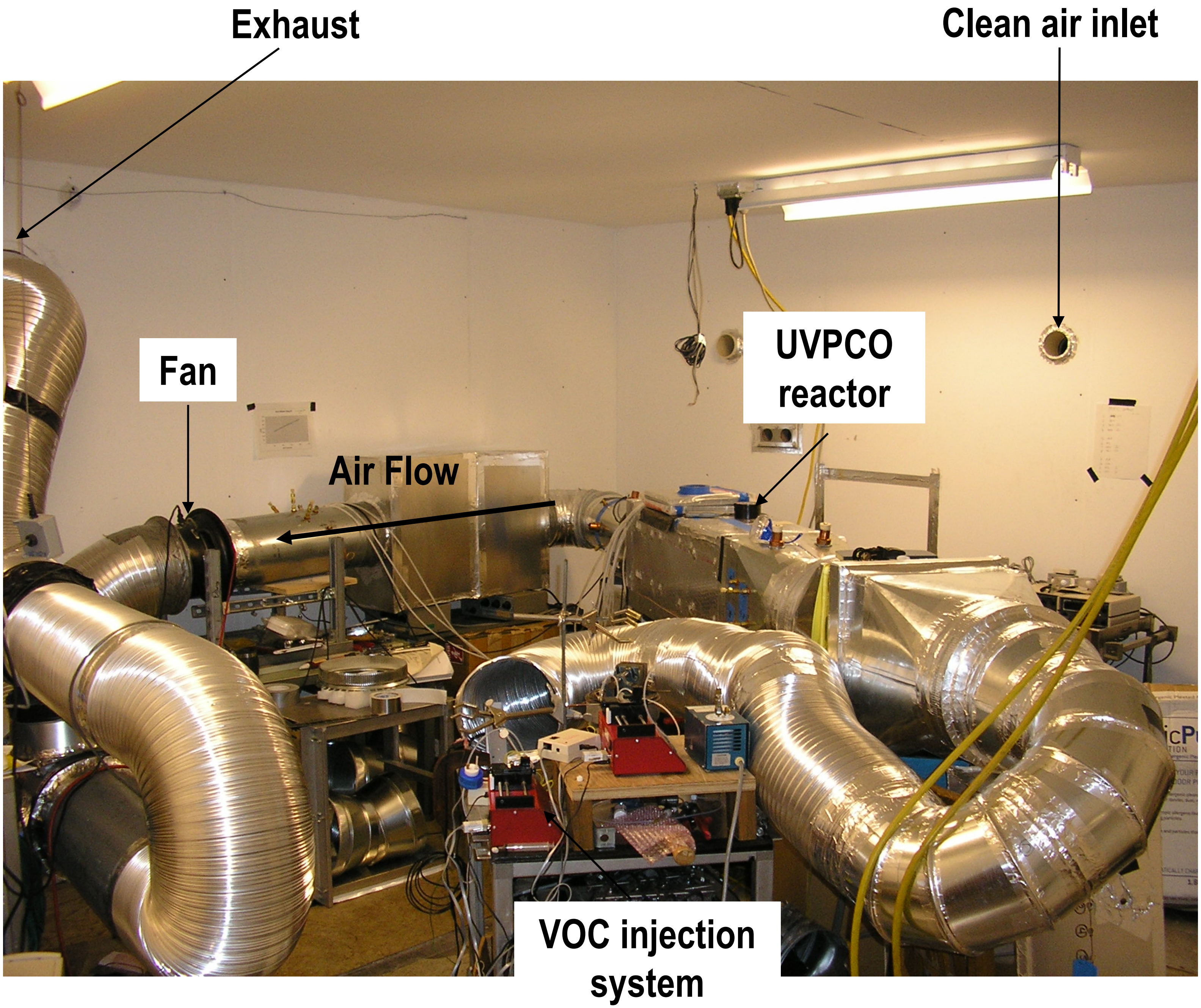
# Honeycomb monolith



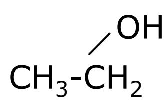
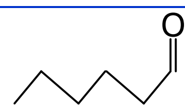
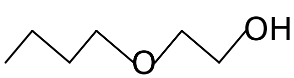
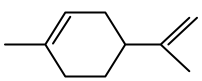
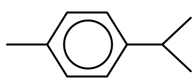
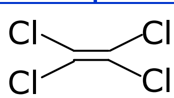
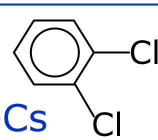

D: a volatile organic compound (VOC)


Exhaust
Clean air inlet
Fan
UVPCO reactor
Air Flow
VOC injection system

# Realistic VOC mixtures

❶ 28 VOCs typical of office buildings

OB

| | |
|---|---|
|  Alcohols |  Carbonyls |
|  Glycol ethers |  Alkanes |
|  Terpenes |  Aromatics |
|  Halogenated VOCs  | |

❷ Mixture of common cleaning products

CP

| | |
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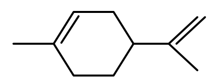
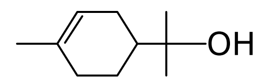
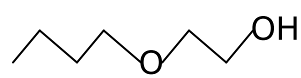
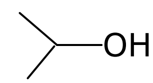
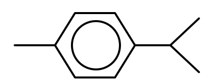
|  Terpenes |  Terpenoids |
|  Glycol ethers |  Alcohols |
|  Aromatics | |

# Realistic VOC mixtures

❶ 28 VOCs typical of office buildings

OB

Ethanol
Isopropanol
1-Butanol
Phenol
Ethylhexanol

Acetone
2-Butanone
MIBK
Hexanal

$CS_2$

MTBE

2-Butoxyethanol

Toluene
m-Xylene
1,2,4-Trimethylbenzene

n-Nonane
n-Decane
n-Undecane
n-Dodecane

TCE
PCE
DCM
Trichlorofluoromethane (R-11)
1,1,1-Trichloroethane
1,2-Dichlorobenzene

Limonene

Decamethylciclopentasiloxane ($D_5$)

❷ Mixture of common cleaning products

CP

Isopropanol

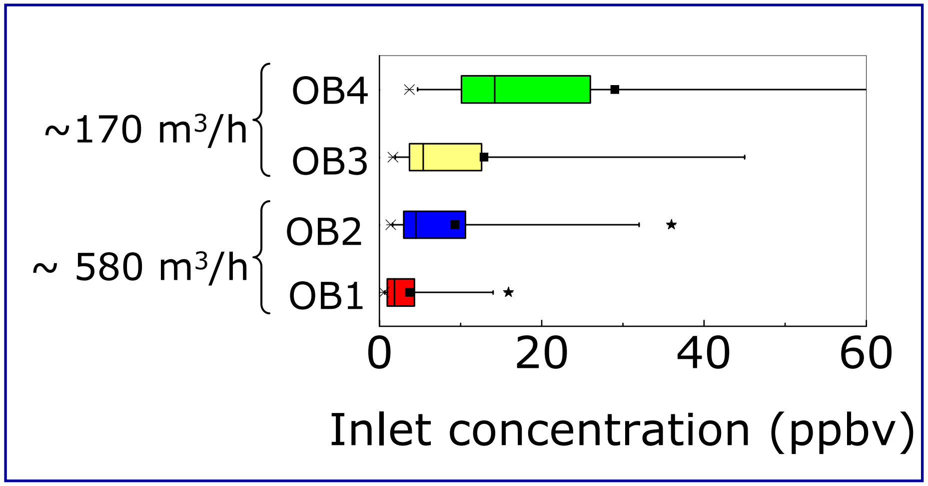
2-Butoxyethanol

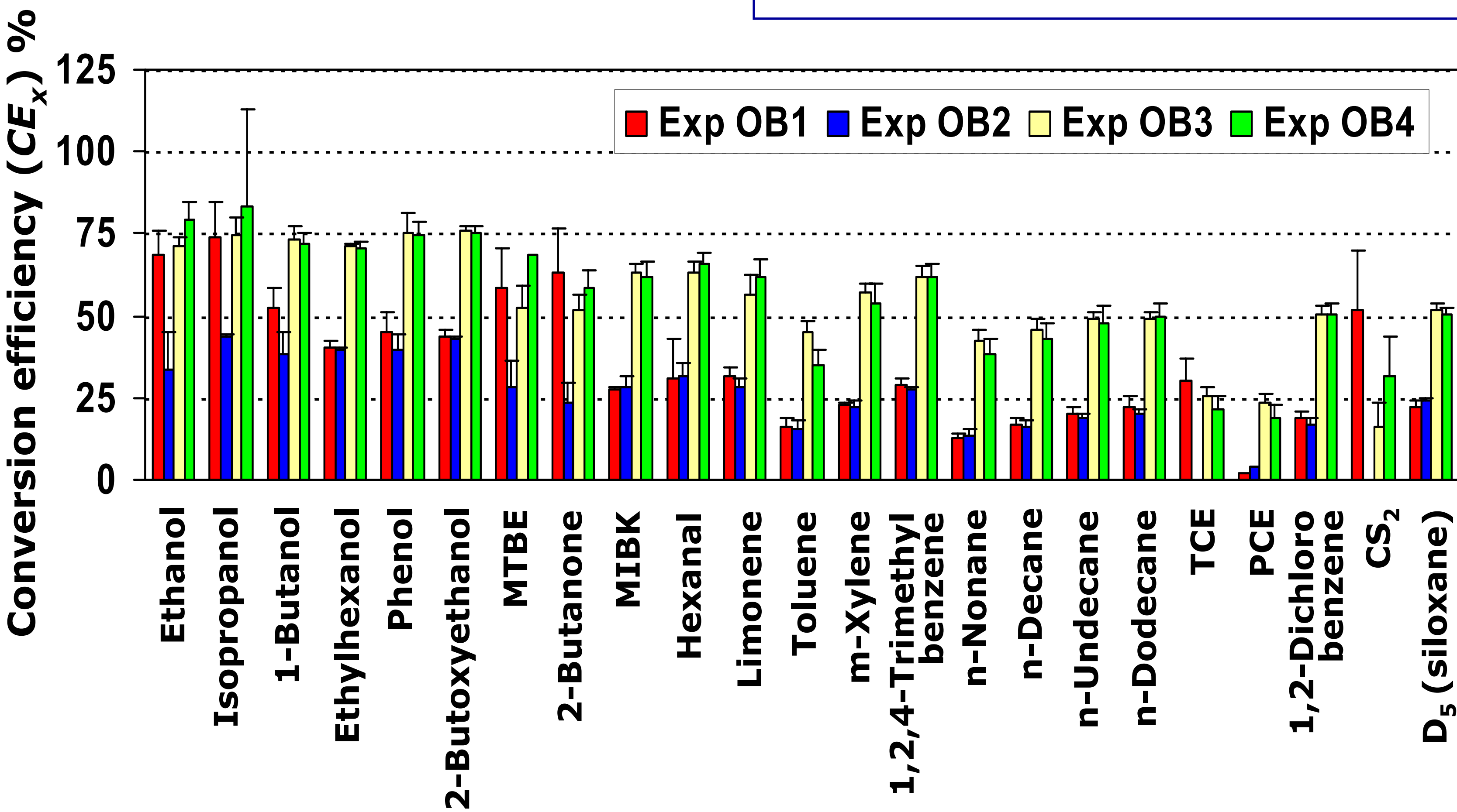
$\alpha$- Pinene
Limonene
Camphene
$\gamma$-Terpinene
Terpinolene

$\gamma$-Terpineol
$\alpha$-Terpineol

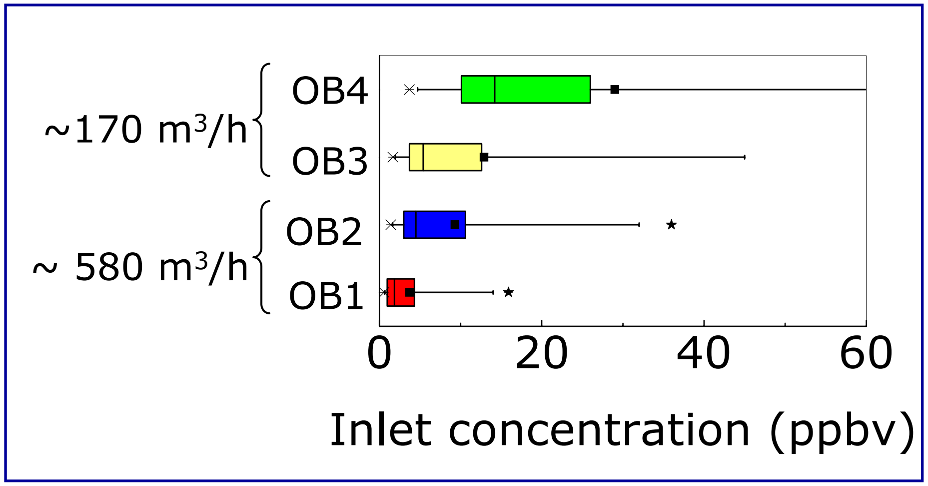
p-Cymene

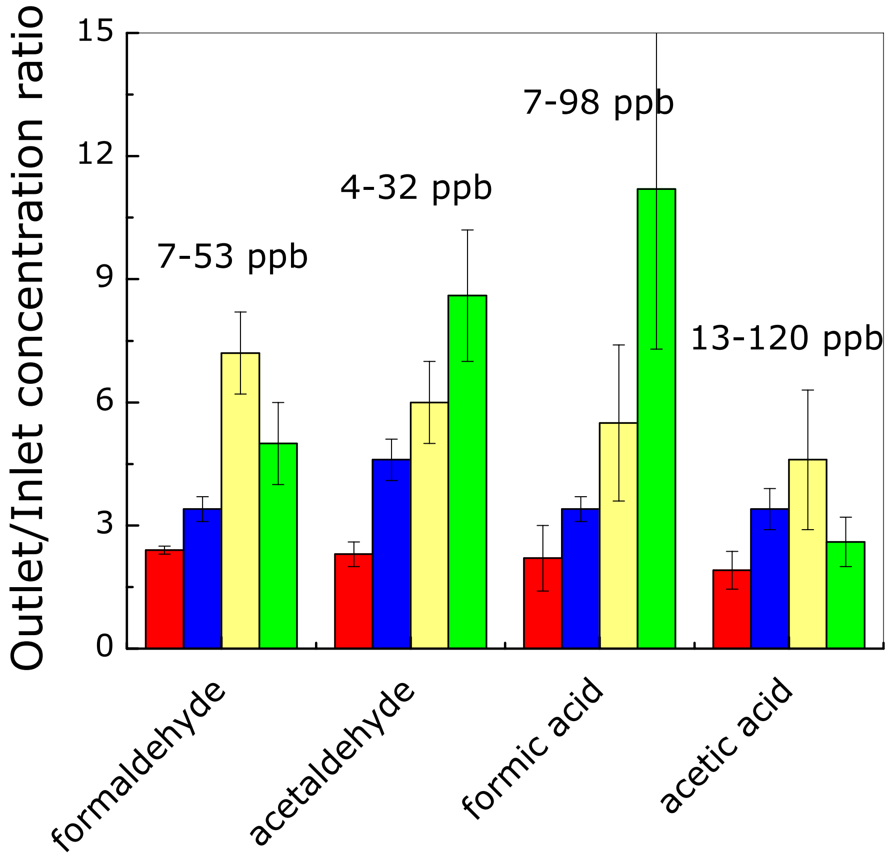
## Office building (OB) mixture



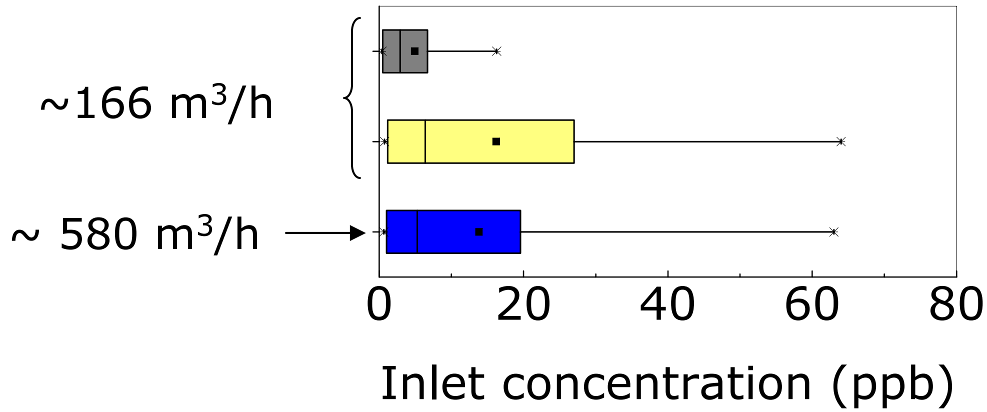



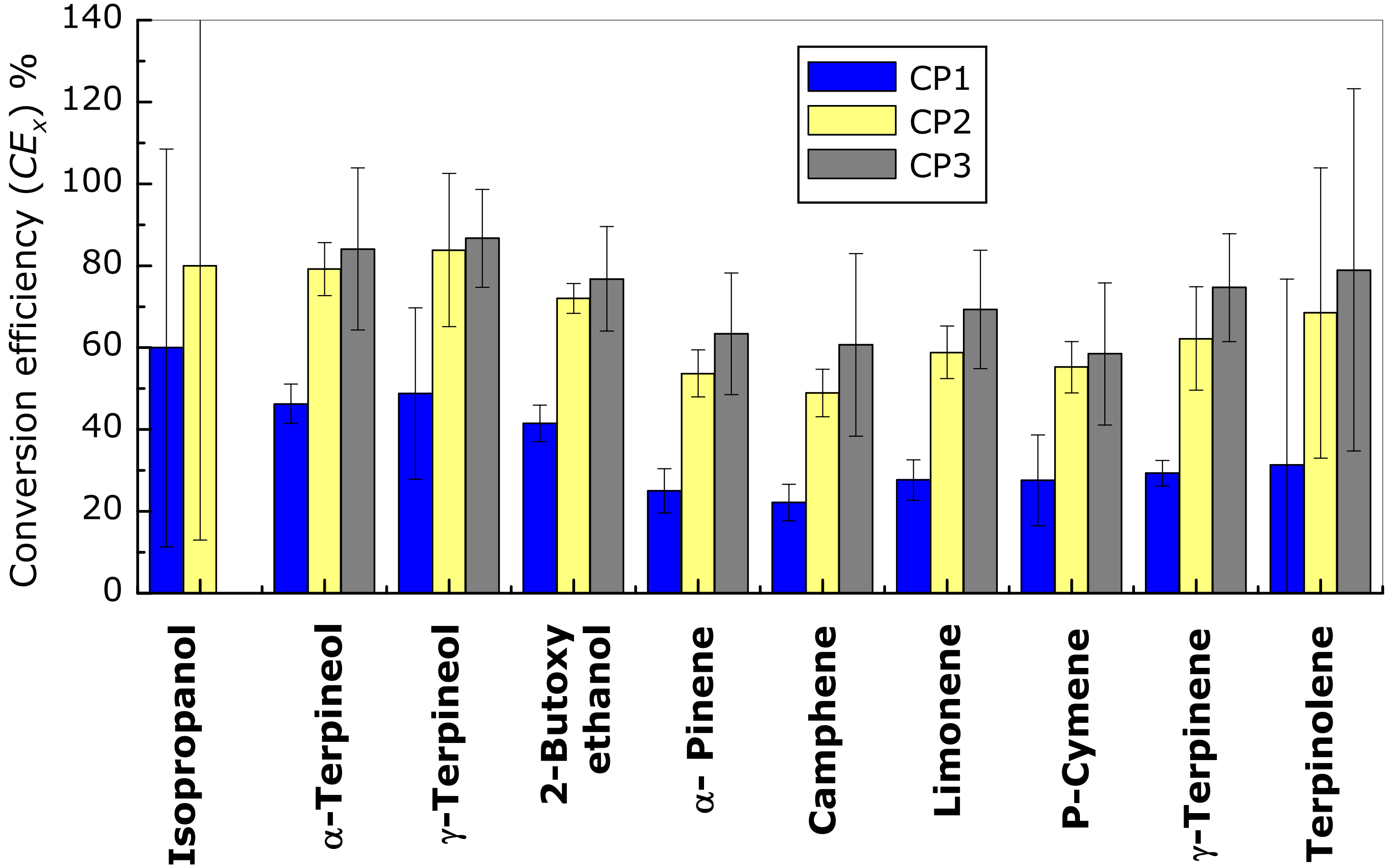
# OB mixture: oxidation products



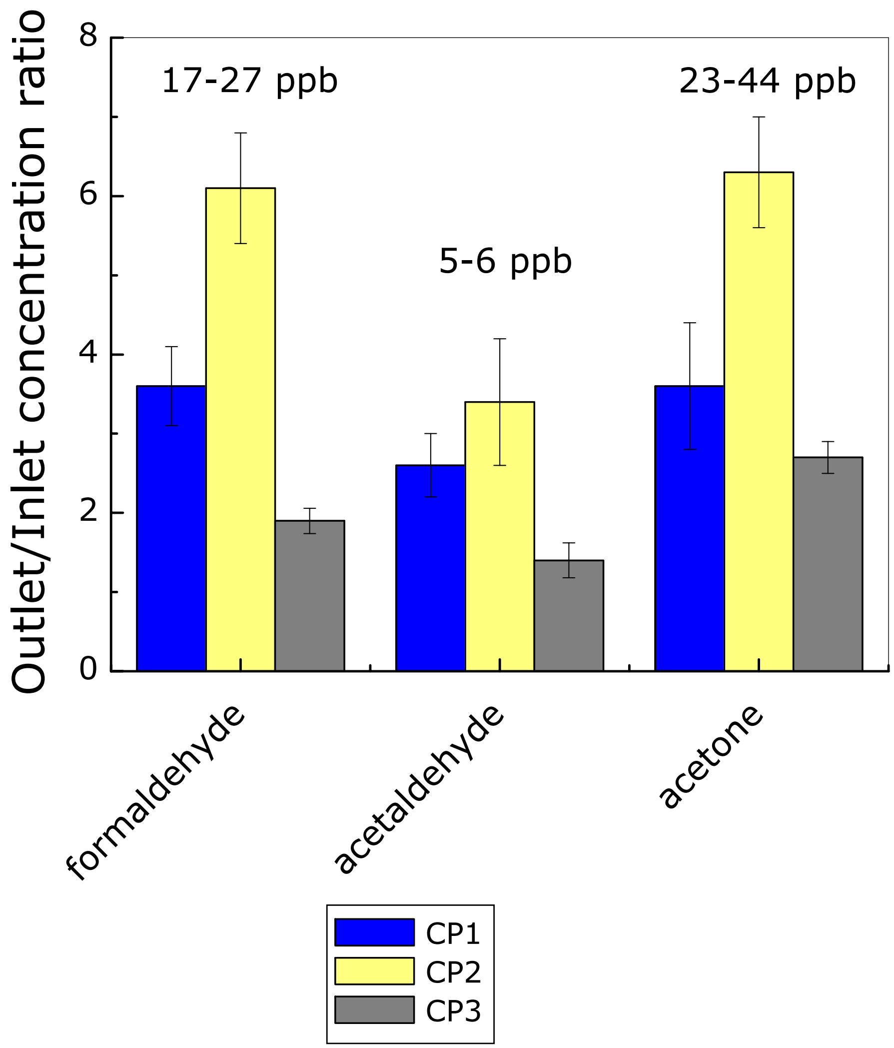



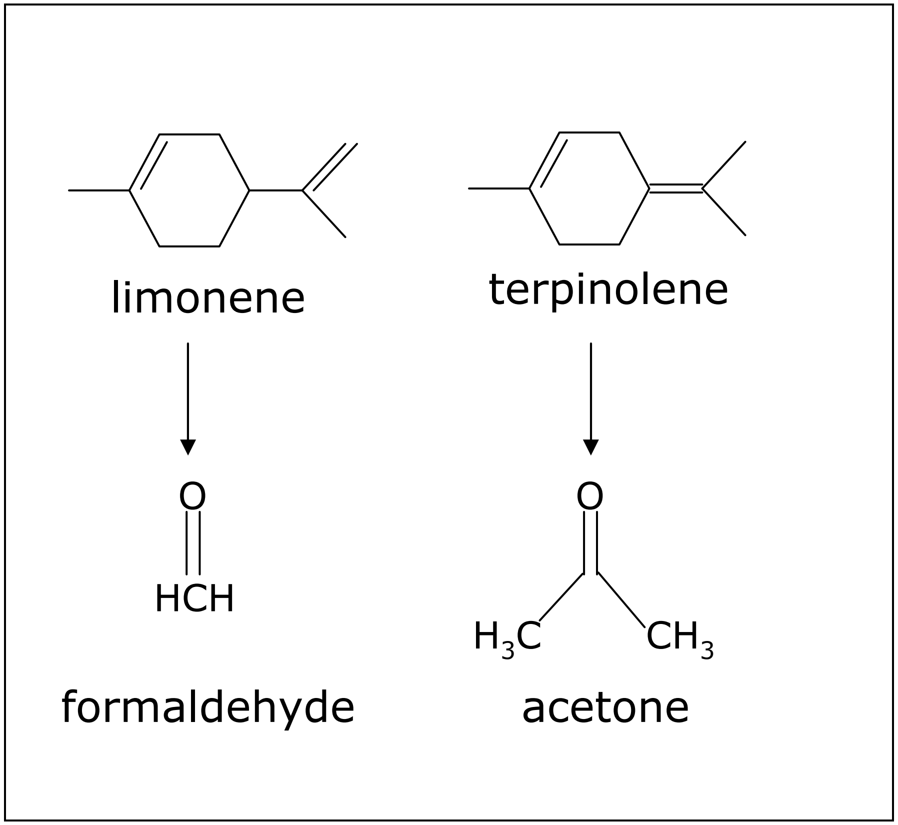
## Cleaning products (CP) mixture:



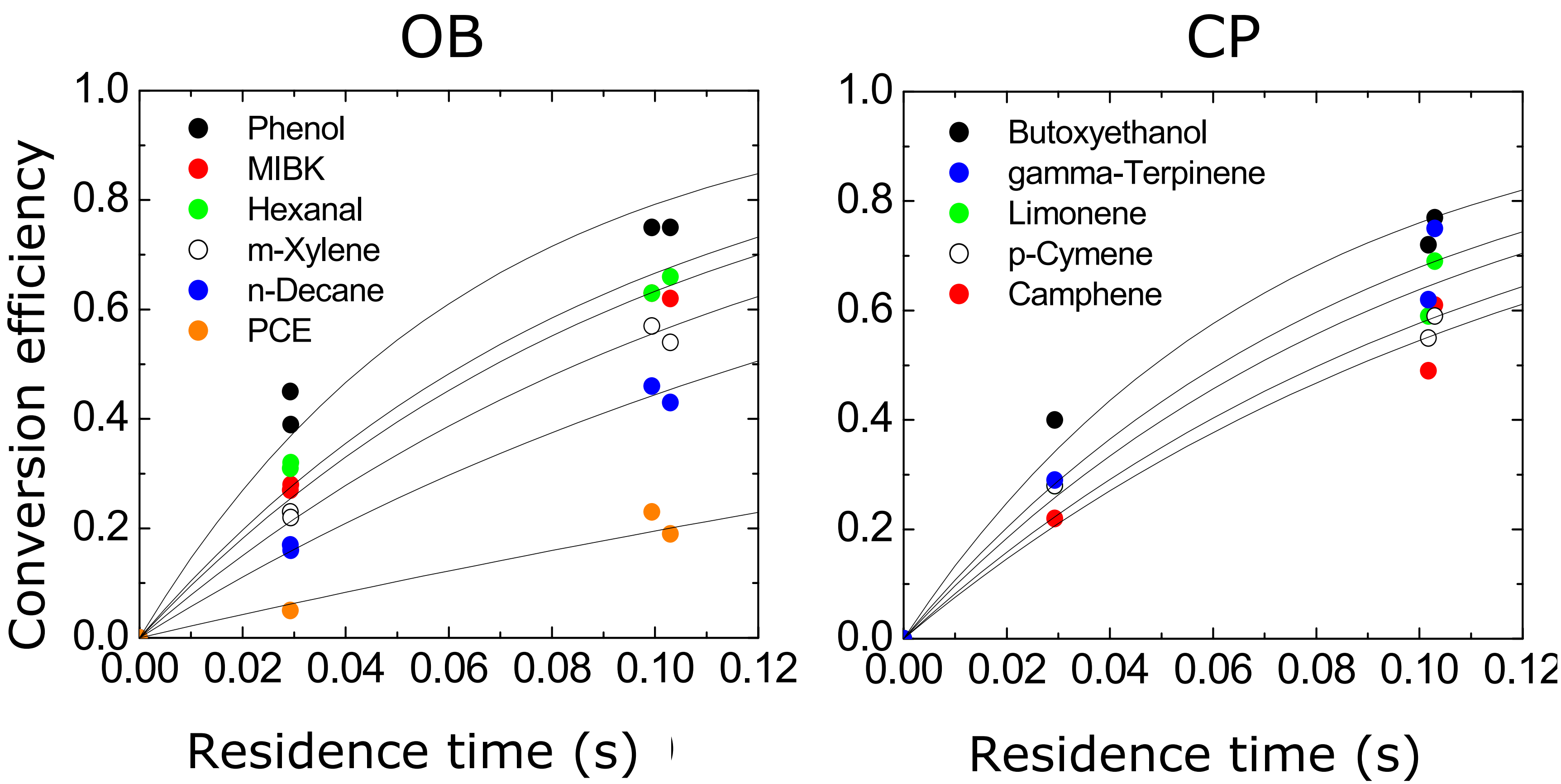
# CP mixture:
# oxidation products



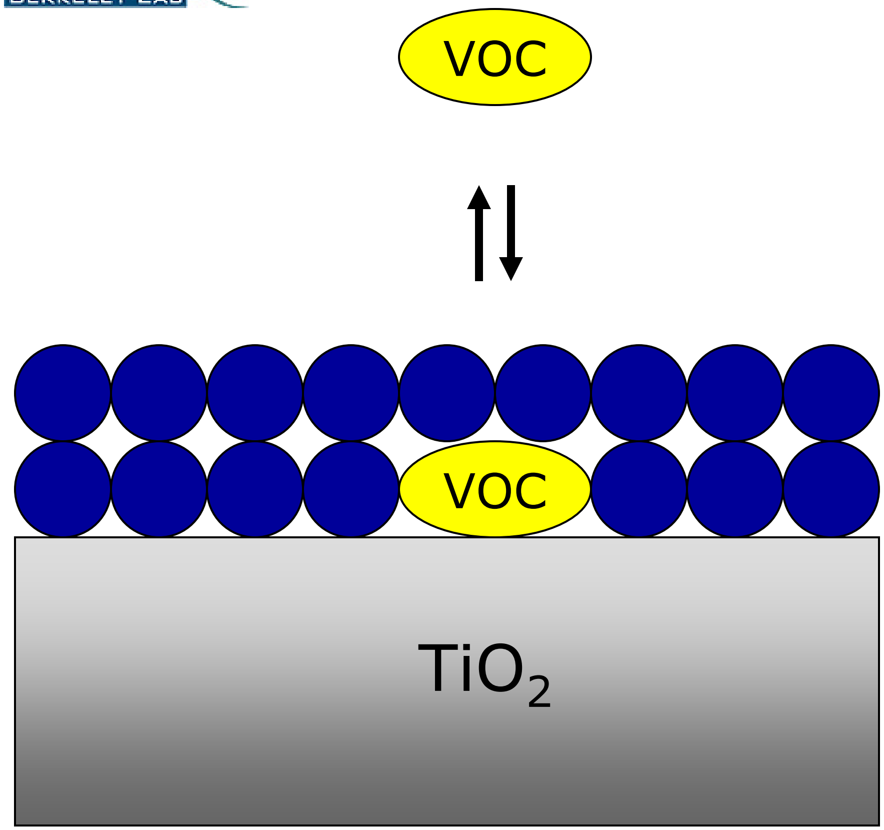



# Influence of residence time on conversion efficiency

$k_x$: reaction rate of individual analyte $x$

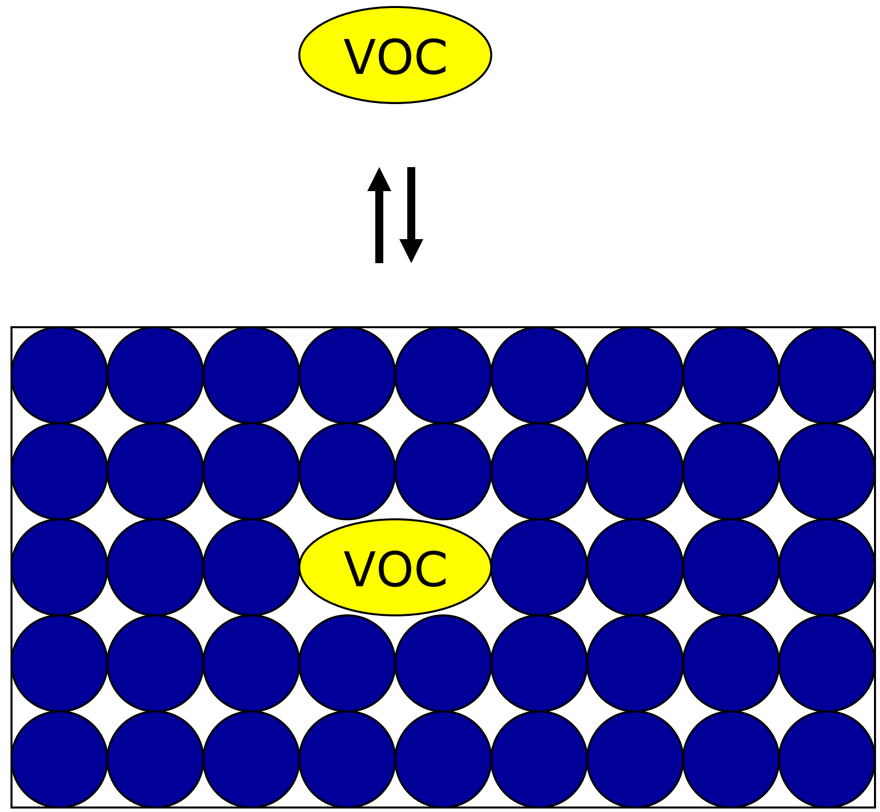



$$\boxed{CE_x = 1\text{-}\exp(-k_x\,\tau)}$$



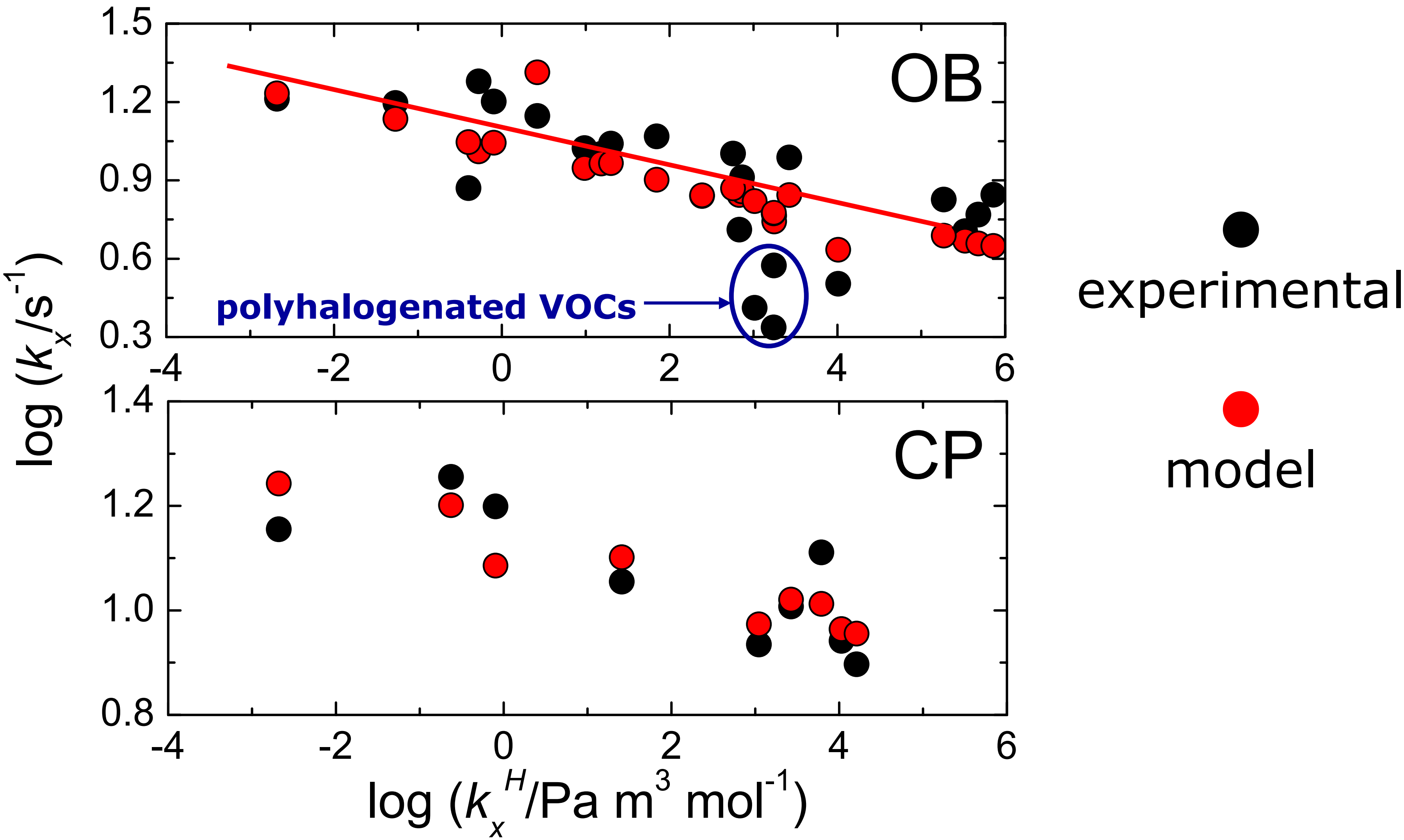

$TiO_2$ surface @ 40-60 % RH

$K_{ads}$



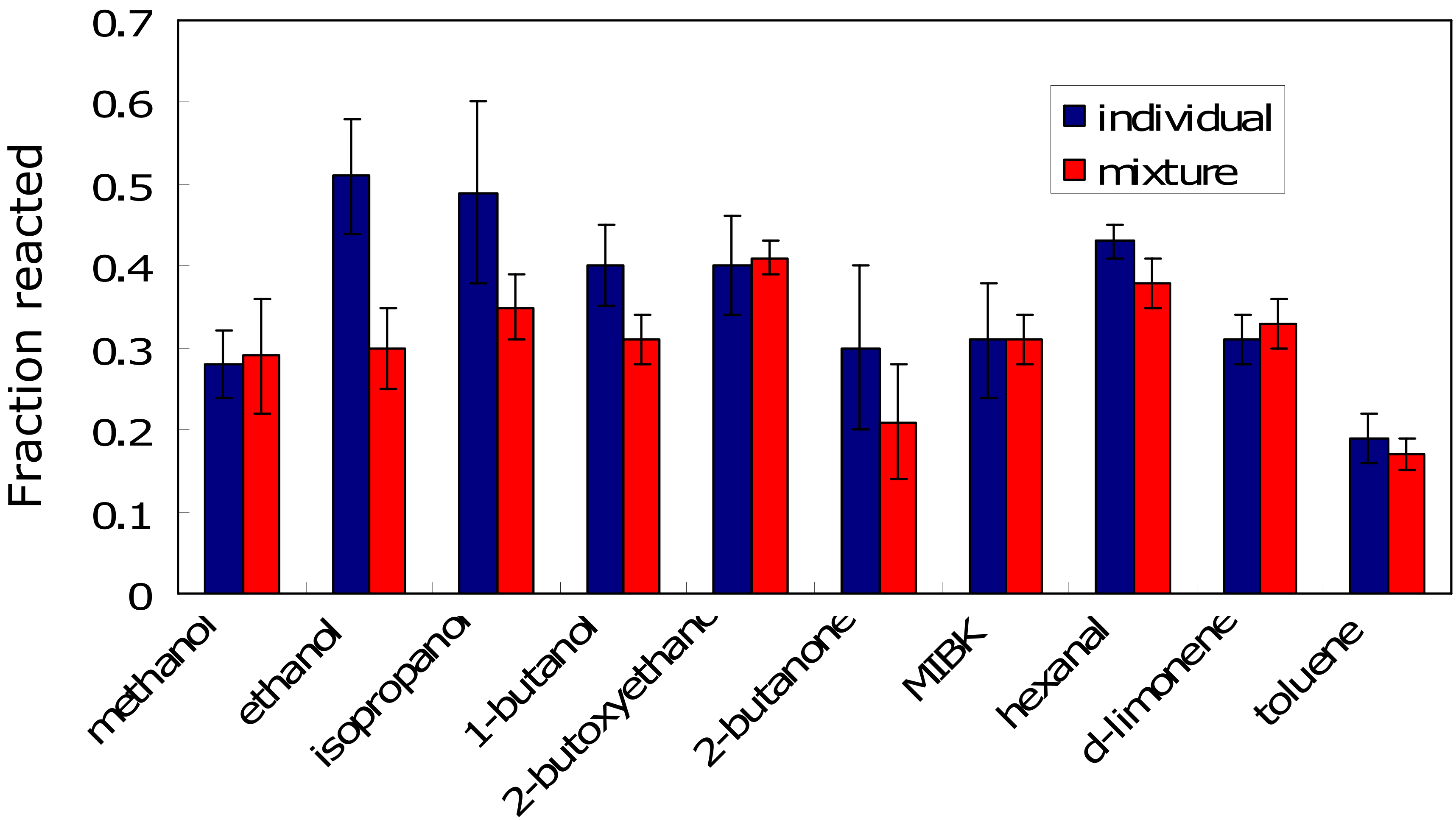

bulk water

$K_X^H$

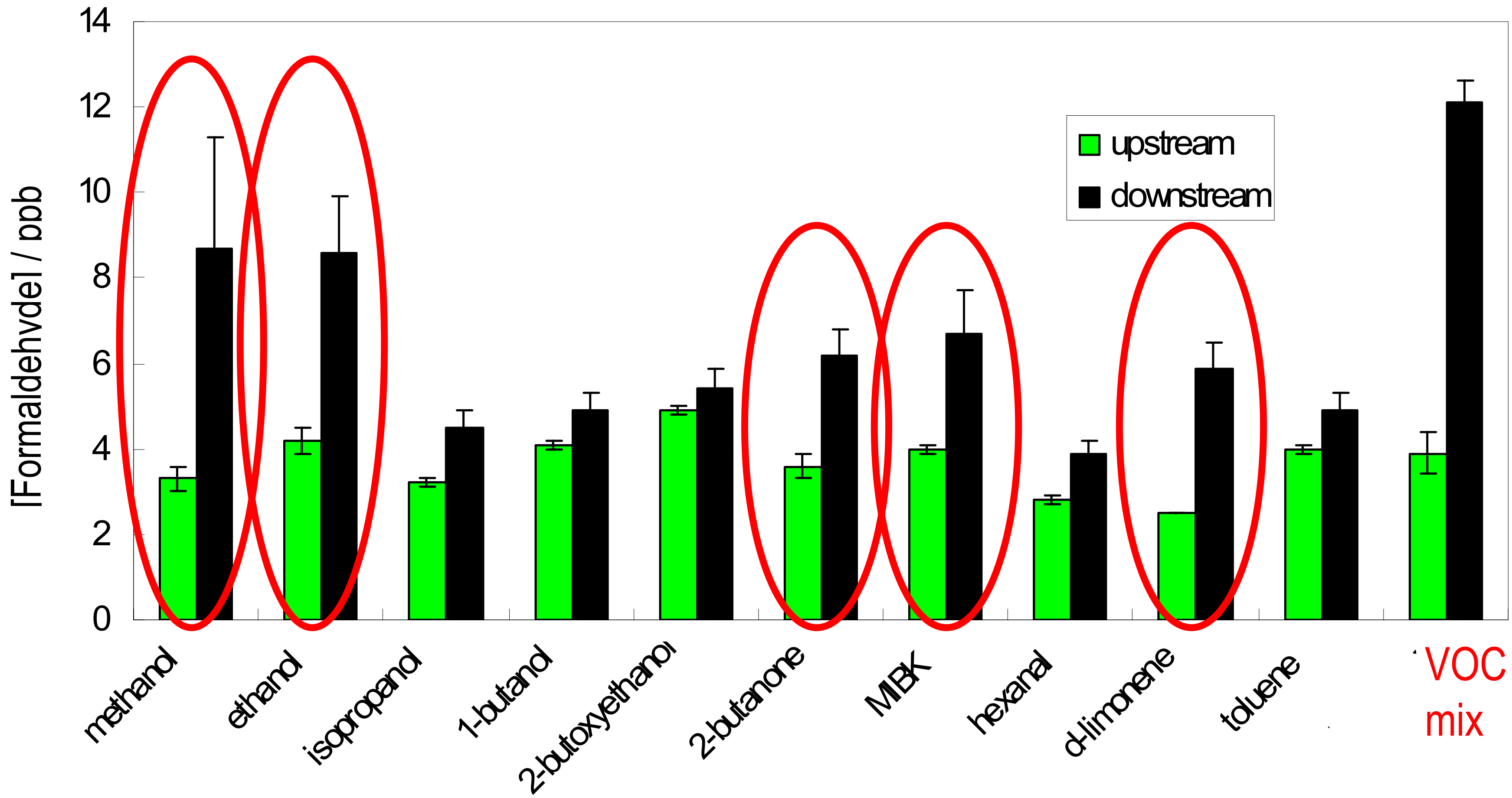



$$\log (k_x) = a + b \log (K_x^H) + c \log (k_x^{OH})$$

# Is there competition between VOCs for $TiO_2$ active sites?



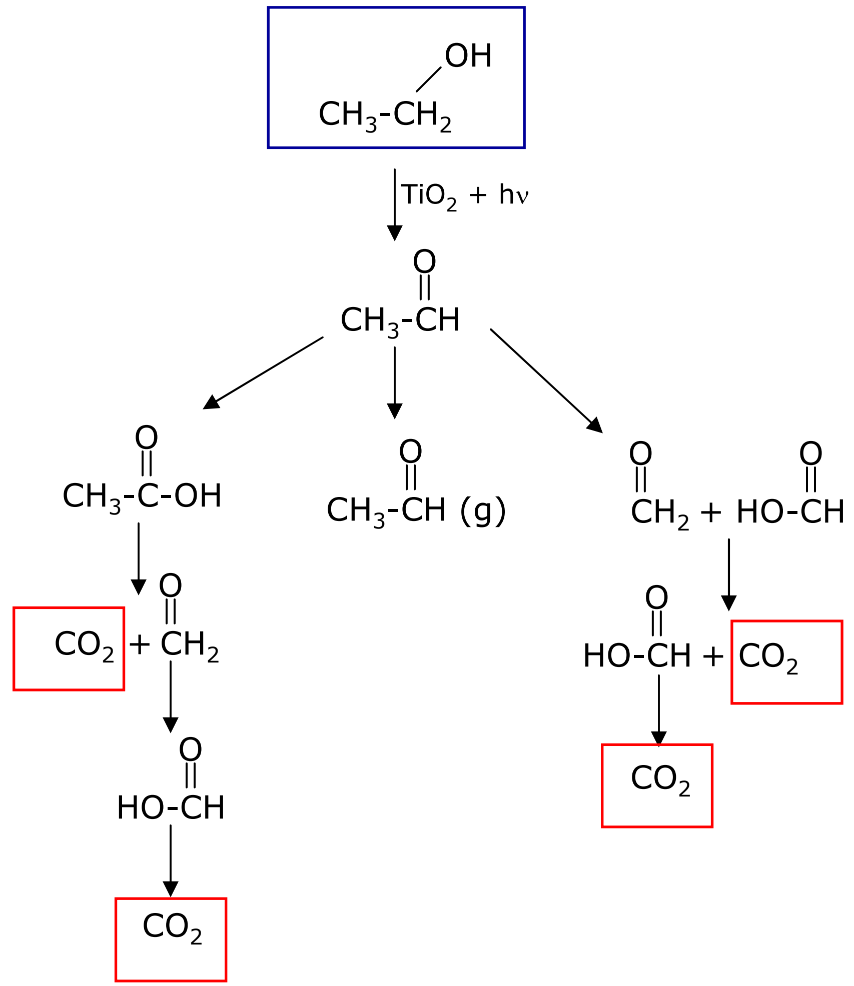
# Byproduct formation: formaldehyde



# Performance of UVPCO

- Removal efficiency of target pollutants
- Formation of undesired oxidation byproducts
- Catalyst inactivation

## Example: mineralization of ethanol



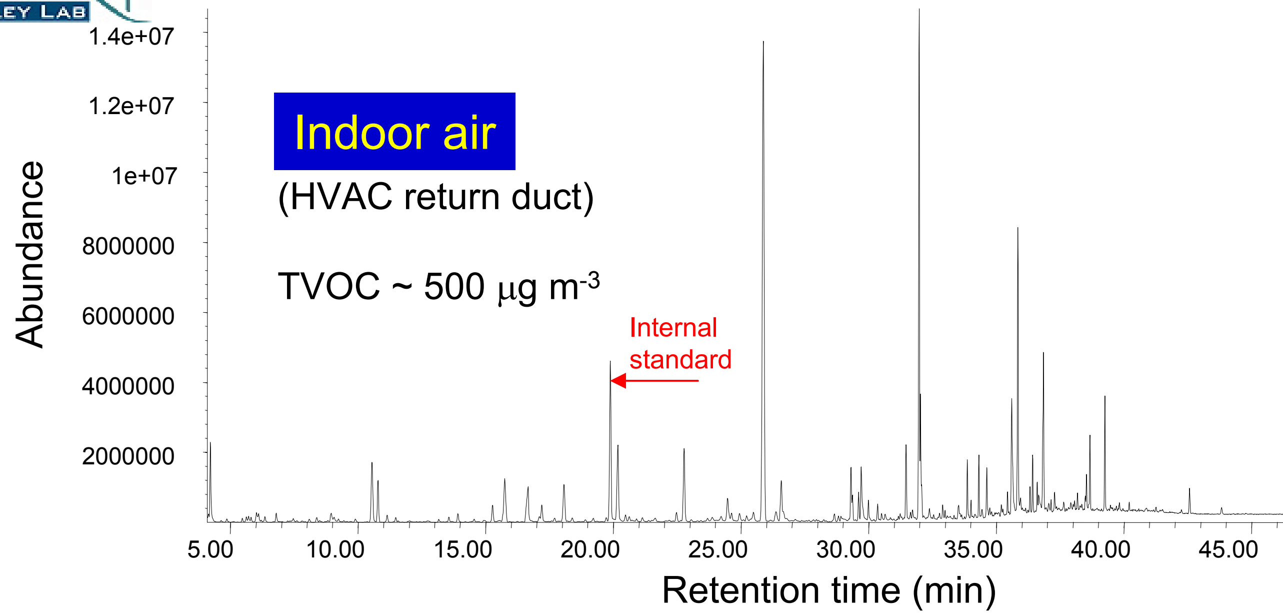
# Summary

- Good single pass conversion efficiencies for nearly all VOCs > 20%; in some cases as high as 80%
- Formation of unwanted byproducts (aldehydes); can be fundamentally attributed to oxidation of certain alcohols, ketones and terpenes.
- Henry's law constant is good correlation parameter to predict reaction rate of individual pollutants
- At concentrations typical of buildings (low ppb range), there is no competition between VOCs for active $TiO_2$ sites

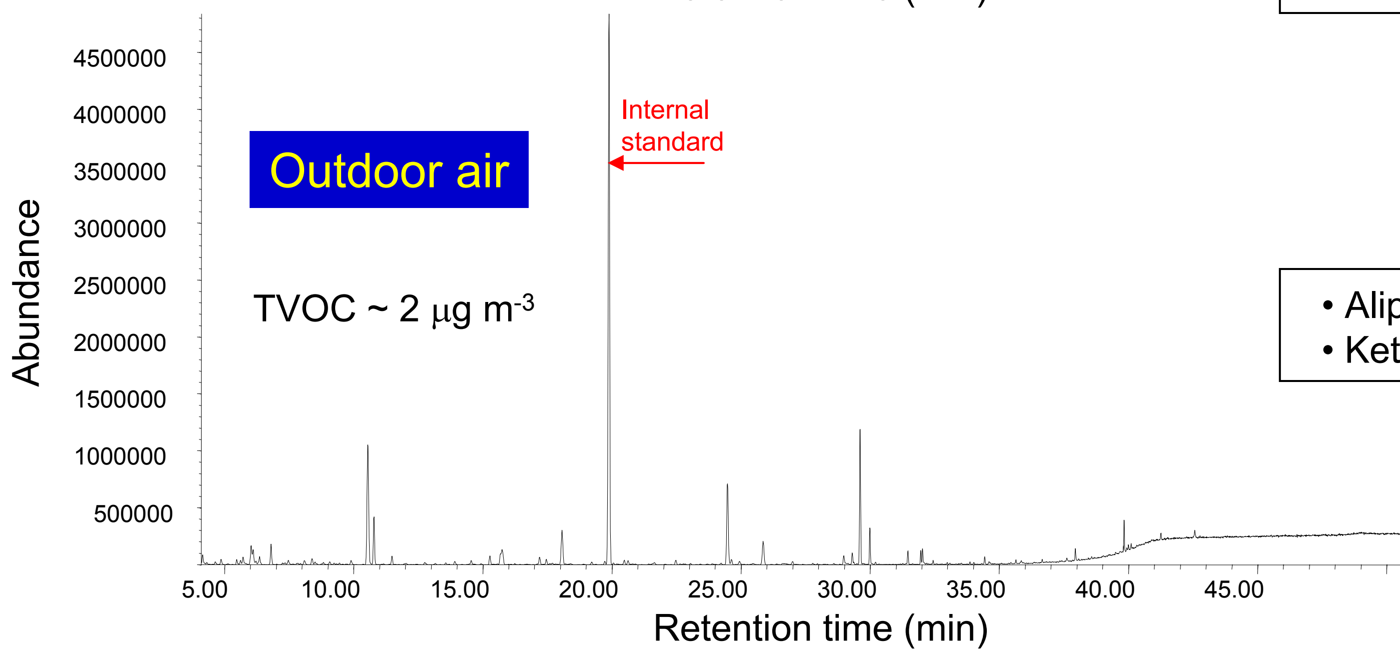
# Questions for discussion: How to define and evaluate the performance of passive PCO ?

- Which are the most critical target pollutants?
- Is $TiO_2$ (anatase) the most appropriate photocatalyst for those target pollutants?
- Should we be concerned about secondary product formation?
- Evaluation of long-term inactivation of catalyst. Regeneration?
- Effect of relative humidity on catalyst performance
- Cost analysis

# Raw data: office building in Los Angeles



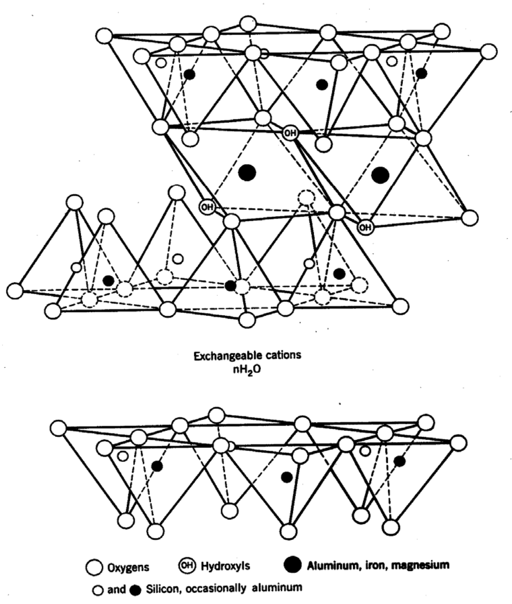

- Alcohols
- Aliphatic hydrocarbons
- Aldehydes
- Ketones
- Aromatic hydrocarbons
- siloxanes
- Ethylene glycols
- Glycol ethers
- Light PAHs (naphtalenes)
- Terpenoids
- Phenols
- Phthalate esters
- … (others)…



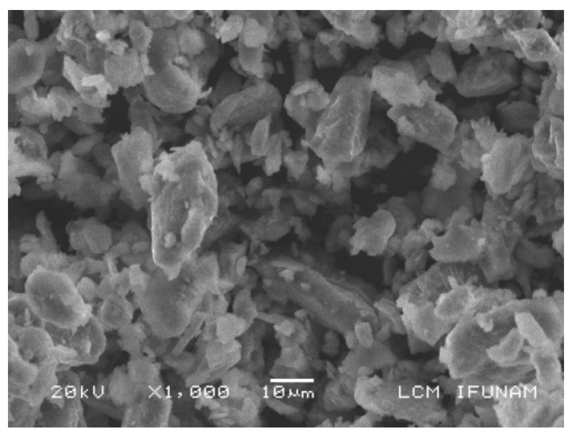

- Aliphatic hydrocarbons
- Ketones

# Composite photocatalysts materials

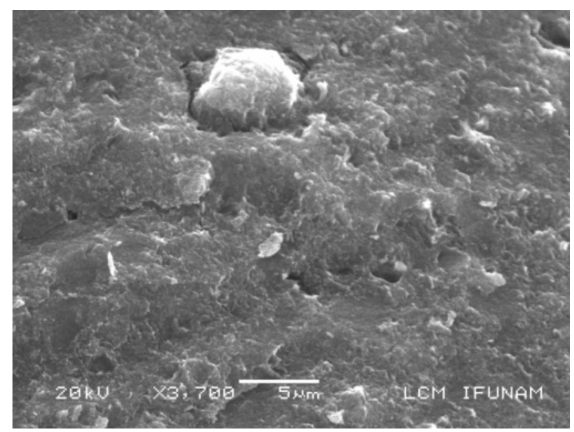
- PICADA project (Strini et al, 2005):
  $TiO_2$-containing cementitious materials:
  - cement rendering (cement + lime + sand)
  - mineral paint
- $TiO_2$-pillared clays



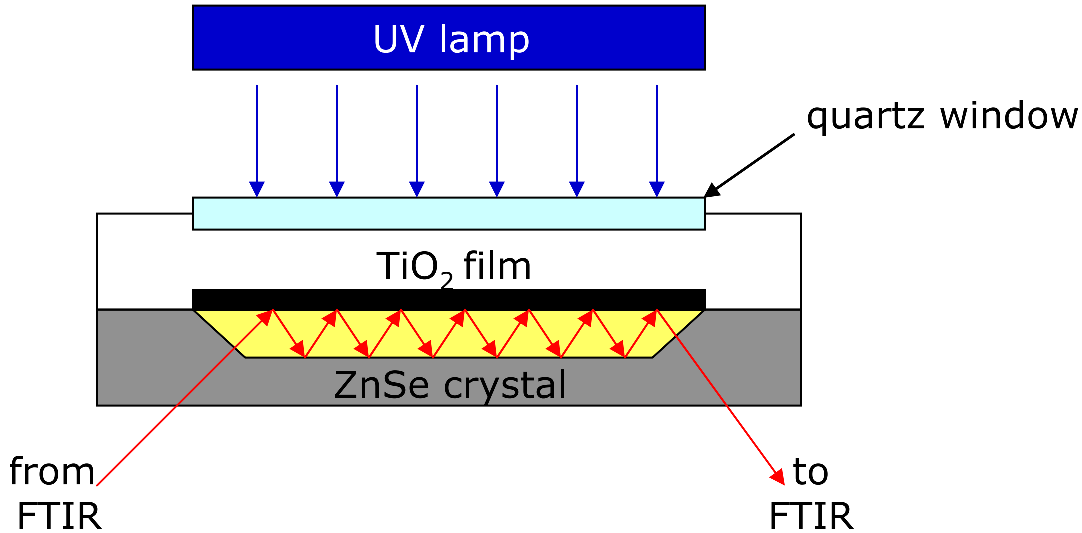

Hectorite

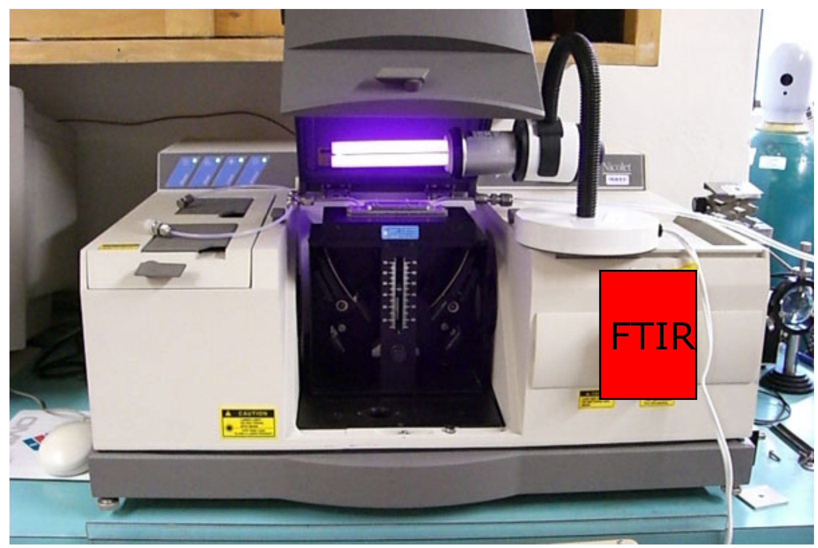



$TiO_2$ - Hectorite

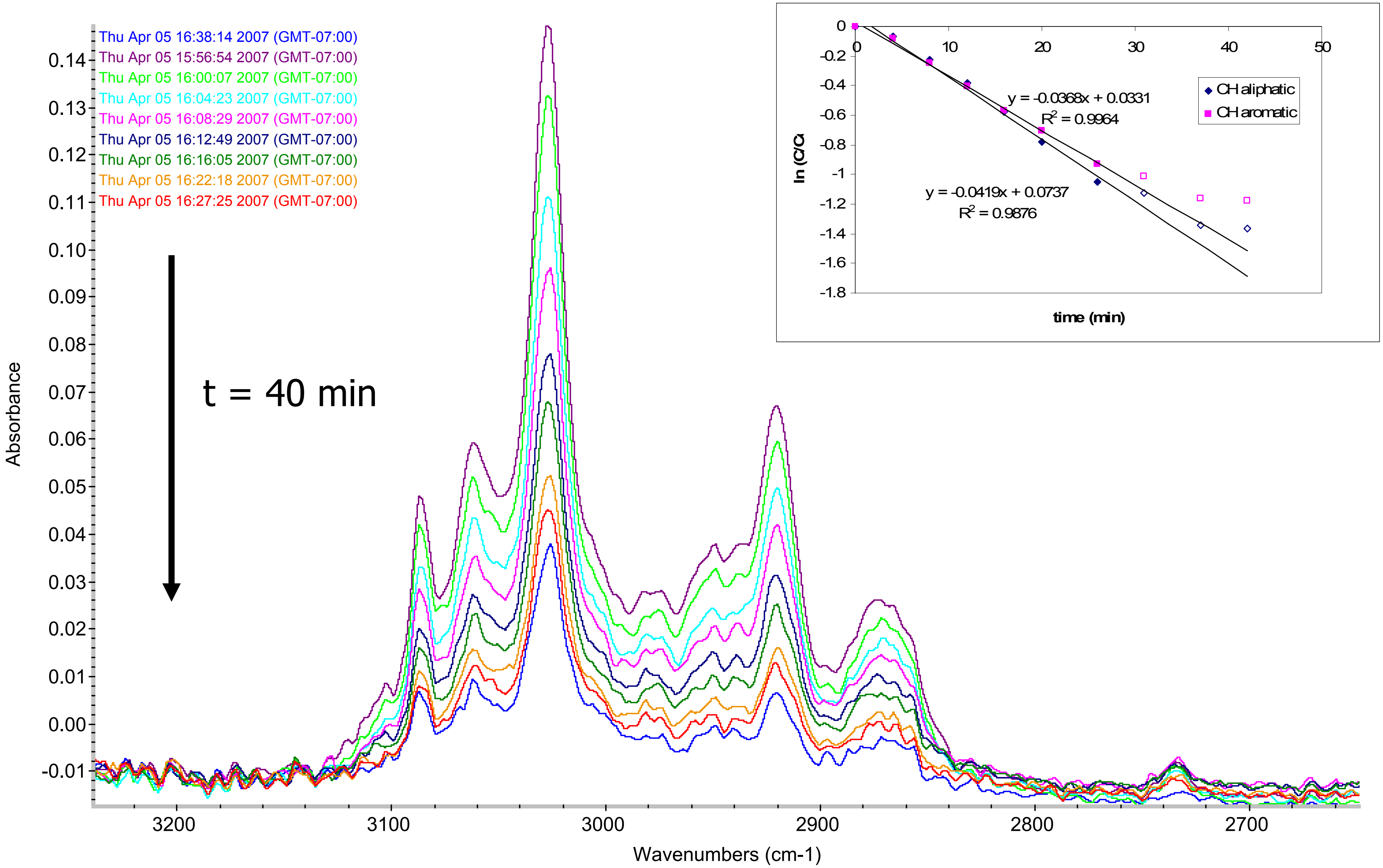


# Attenuated total reflection-FTIR chamber



# Attenuated total reflection-FTIR spectra



# Acknowledgements

David Faulkner
Toshifumi Hotchi
Raymond Dod

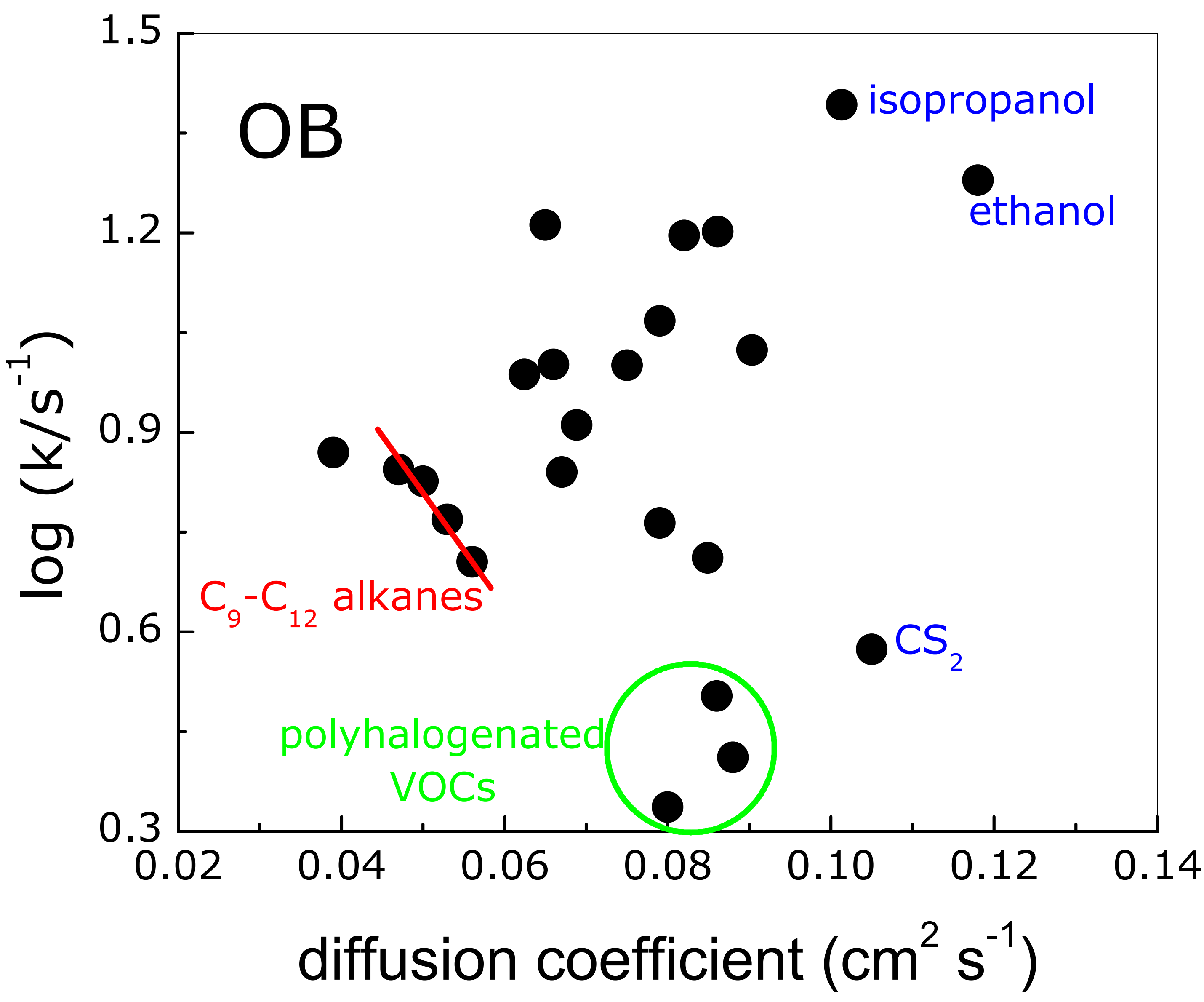
Stephen O. Hay
Norberto Lemcoff

Javiera Cervini-Silva
Daria Kibanova

Funding: US Department of Energy (DOE)
Building Technologies Program
Terry Logee, Program Manager
Contract No. DE-AC02-05CH1123

Laboratory Directed Research and Development
(LDRD) program, LBNL.

# Are kinetics controlled by mass-transfer?



# Are kinetics controlled by the chemical step?

Langmuir - Hinshelwood

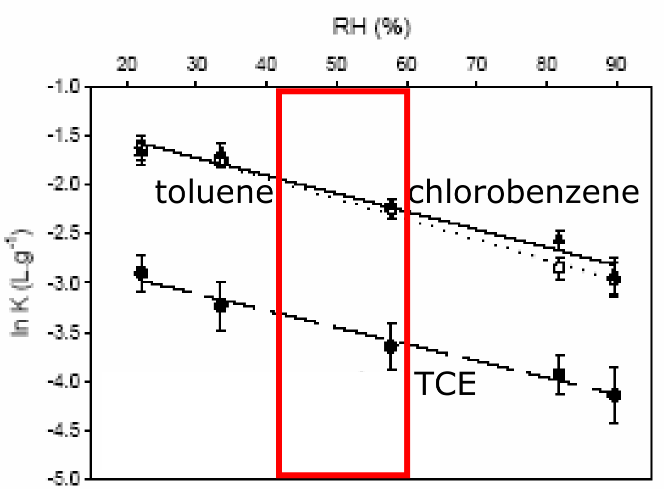
$$\frac{\partial[X]}{\partial t} \sim k\theta_X\theta_{O_2}$$

$$\theta_X = \frac{K_{ads}[X]}{(1+K_{ads}[X])}$$

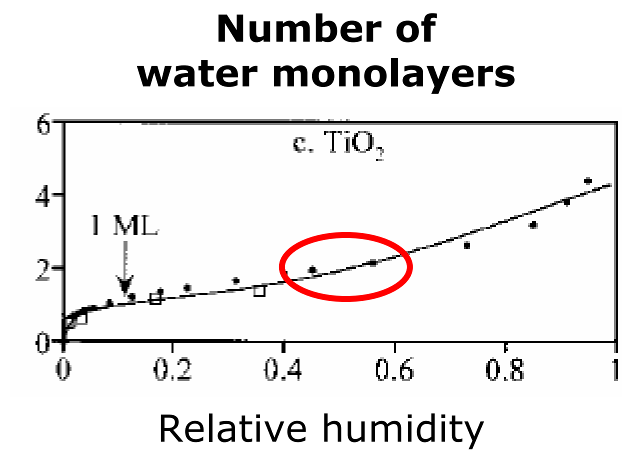
Parameters: $k_x^{OH}$ ?

Apparent binding constant

## $K_{ads}$ depends on surface water




Demeestere et al. *Chem. Eng. Sci.* **2003**, *58*, 2255-2267.




Goodman et al. *J. Phys. Chem. A* **2001**, *105*, 6443-6457.

# VOC removal efficiency