Methods Used to Collect and Interpret Raw Data from a GAC Adsorption Pilot Plant Study to Identify Fundamental Design and Operating Criteria

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Brown AND Caldwell

Looking Forward

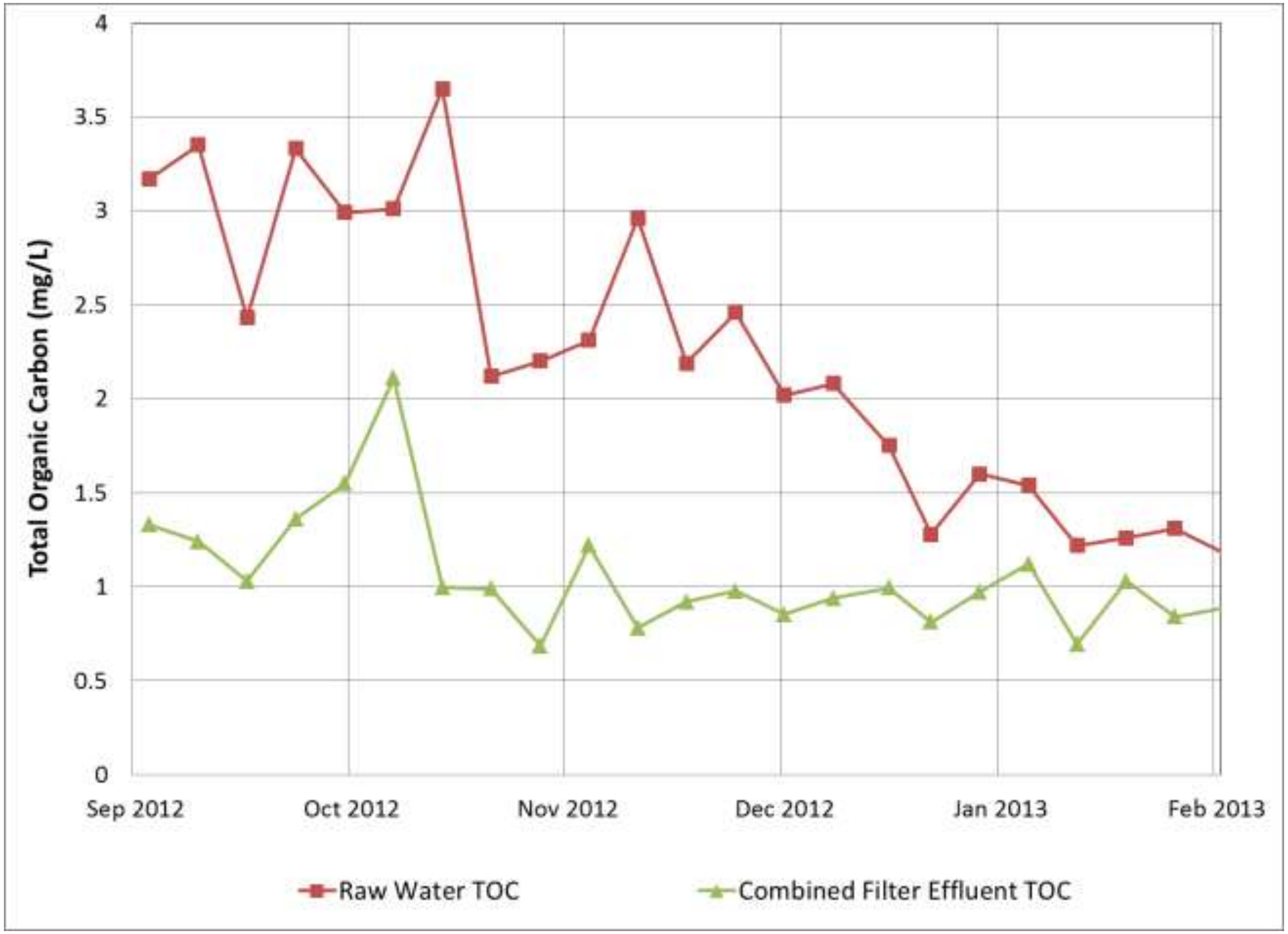
- The Setup
- Mountains of Data
- Typical Analysis
- Expanded Analysis
- Broad and Useful Interpretations

The Setup

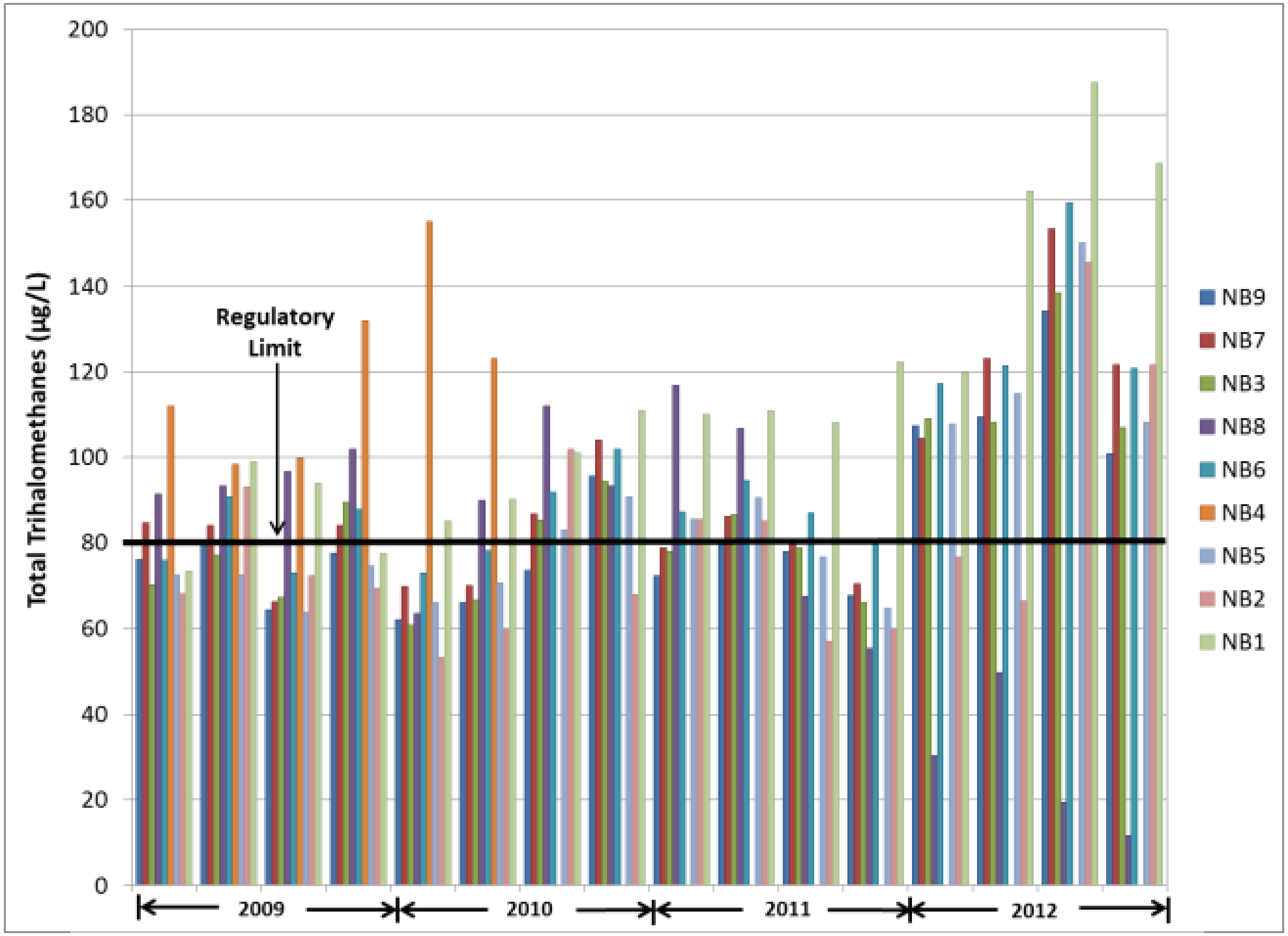
Testing Performed on a 13 MGD Pacific Island WTP

Warm Tropical Water
Lots of Organics!

TOC Data Seems Modest



However, Problems with TTHM!



GAC Adsorption is A Good Option

DBP Reduction Alternatives	
PRIMARY ALTERNATIVE	**Treatment method or operational change**
1	GAC adsorption
2	Magnetic ion exchange (MIEX) filtration
3	Membrane filtration
4	Chloramine disinfection
5	Powdered activated carbon (PAC) addition
6	Use of alternative oxidants for pretreatment (ozone)
SECONDARY ALTERNATIVE	**Treatment method or operational change**
7	Reduced chlorine dosing prior to filtration (prechlorination)
8	Reduced chlorine dosing in treated water (post-chlorination)
9	Use of alternative oxidants for pretreatment (chlorine dioxide)
10	Use of alternative oxidants for pretreatment (potassium permanganate)
11	Enhanced coagulation
12	Increased distribution system water line flushing
13	Tank aeration of DBPs (chloroform only)

Test Program

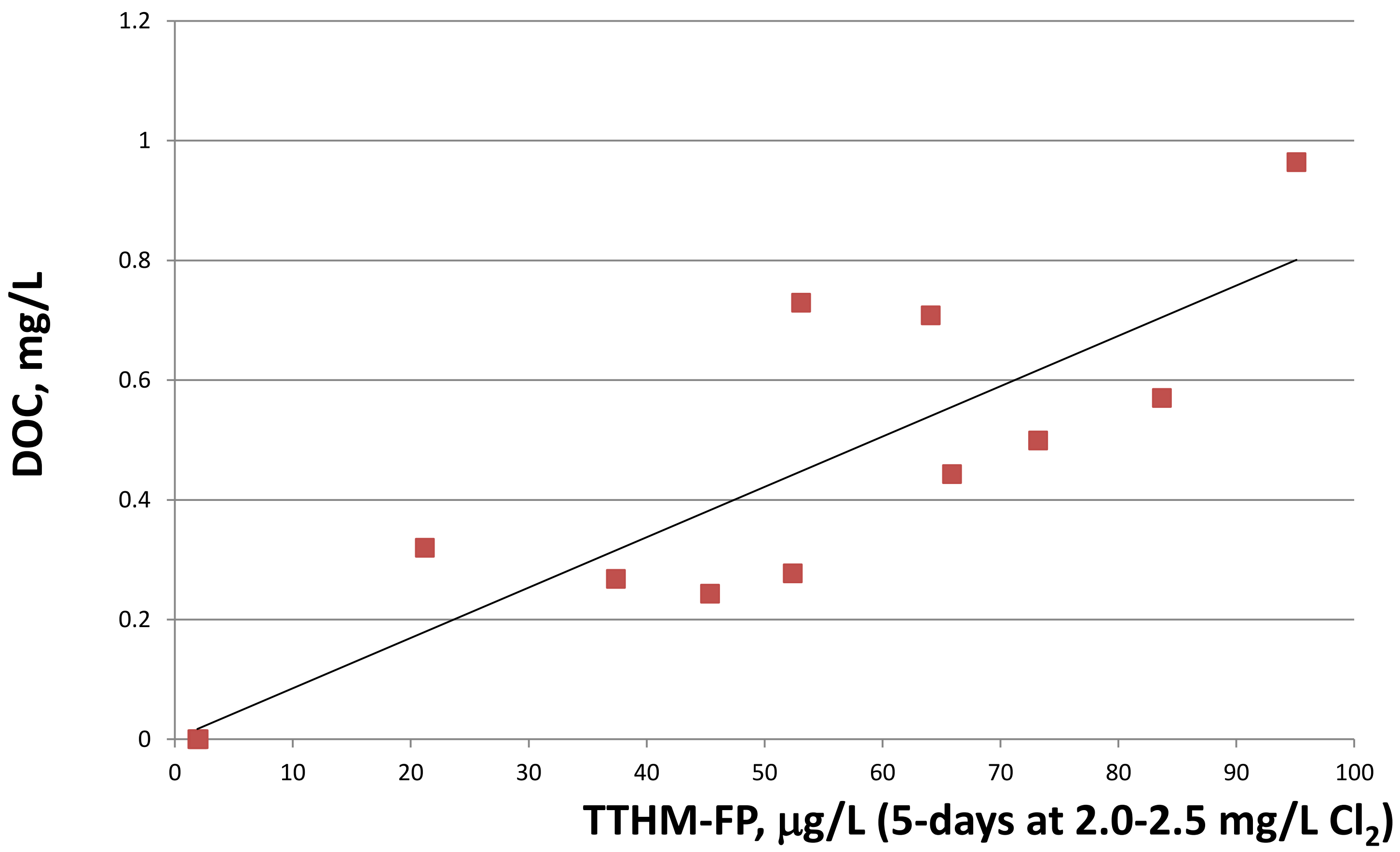
- Isotherm Testing of Various GAC Media
- Determine Adsorber Operating Criteria
  - DOC surrogate for TTHM
  - Breakpoint
  - Breakthrough-assigned to be at half of the TTHM MCL
  - Exhaustion-equivalent to feed stream concentration
- Operate a Single Adsorber for 5 Months
- Collect and Analyze Data
- Interpret Results

Mountains of Data

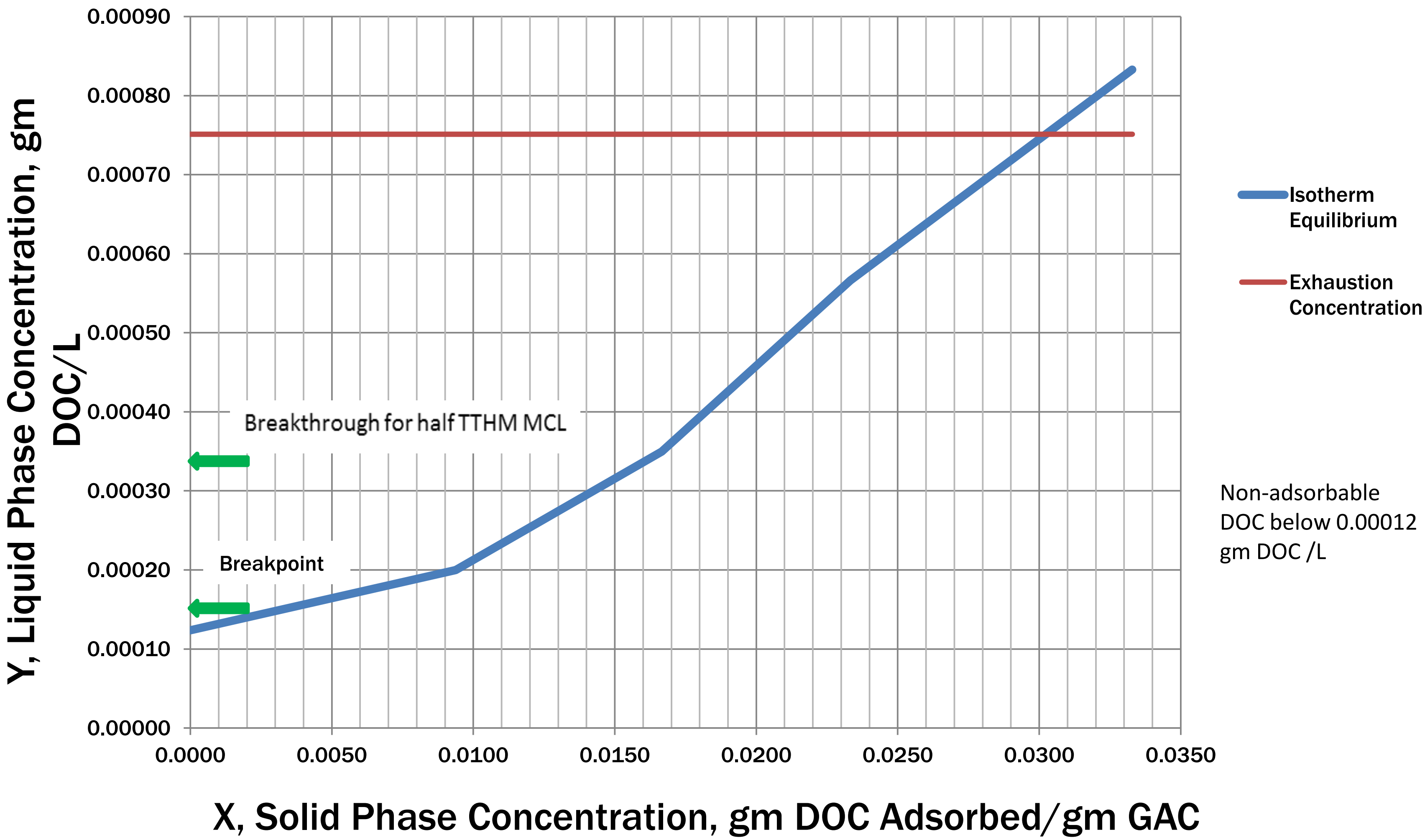
Isotherm Testing

- Performed by Calgon
- Correlated TTHM-FP with TOC and DOC
- Batch Testing of Raw Water with Different Concentrations of Pulverized GAC
  - Filtrasorb 300 (bituminous)
  - Filtrasorb 400 (bituminous)
  - OLC (coconut shell)
- Filtrasorb 400 Proved Best

DOC Correlation with TTHM-FP



DOC Isotherm Equilibrium Graph
Filtrasorb 400



Non-adsorbable DOC below 0.00012 gm DOC /L

Calgon Model 10 Adsorber

10 Foot Diameter

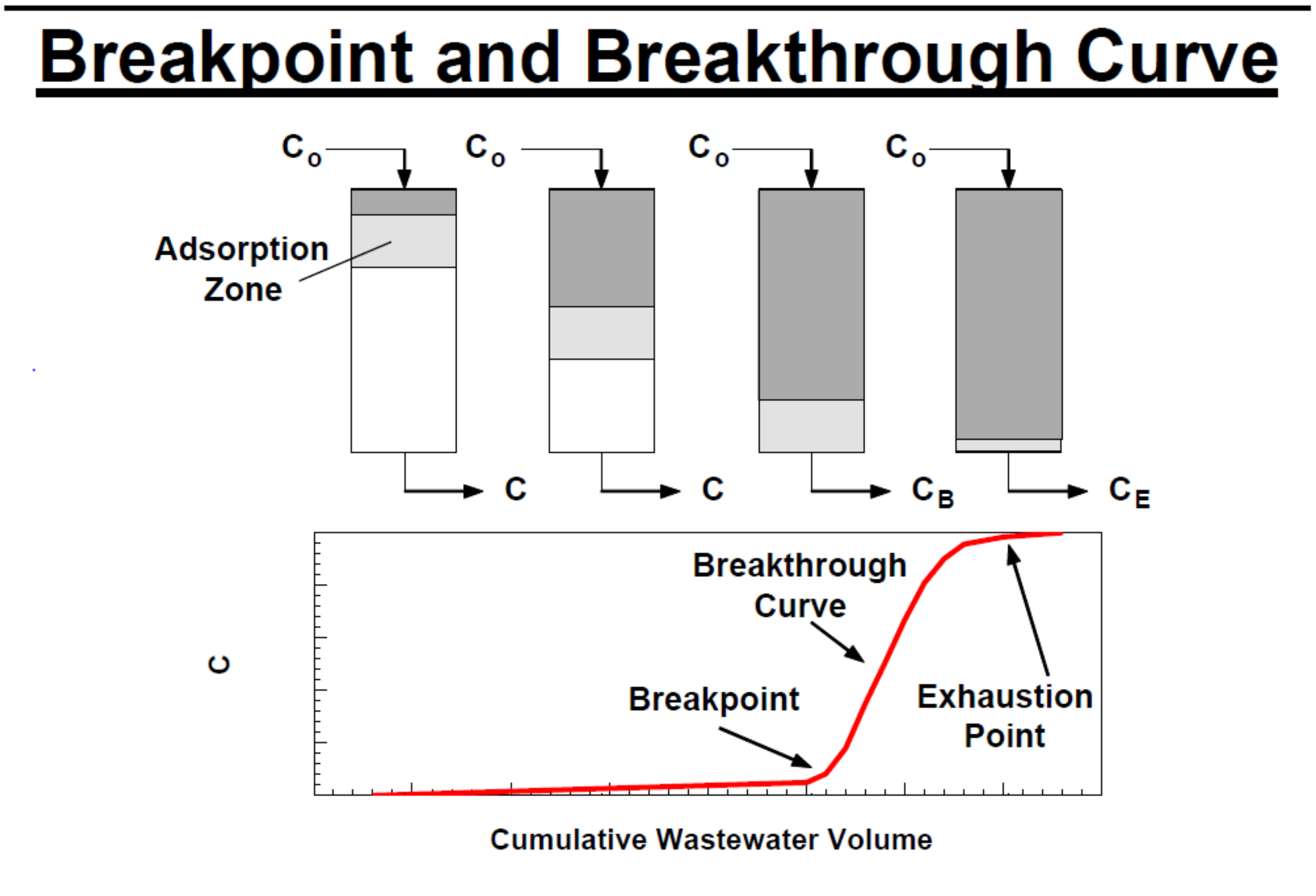
20,000 Pounds

Filtrasorb 400 per Tank

Operated at 0.5 MGD

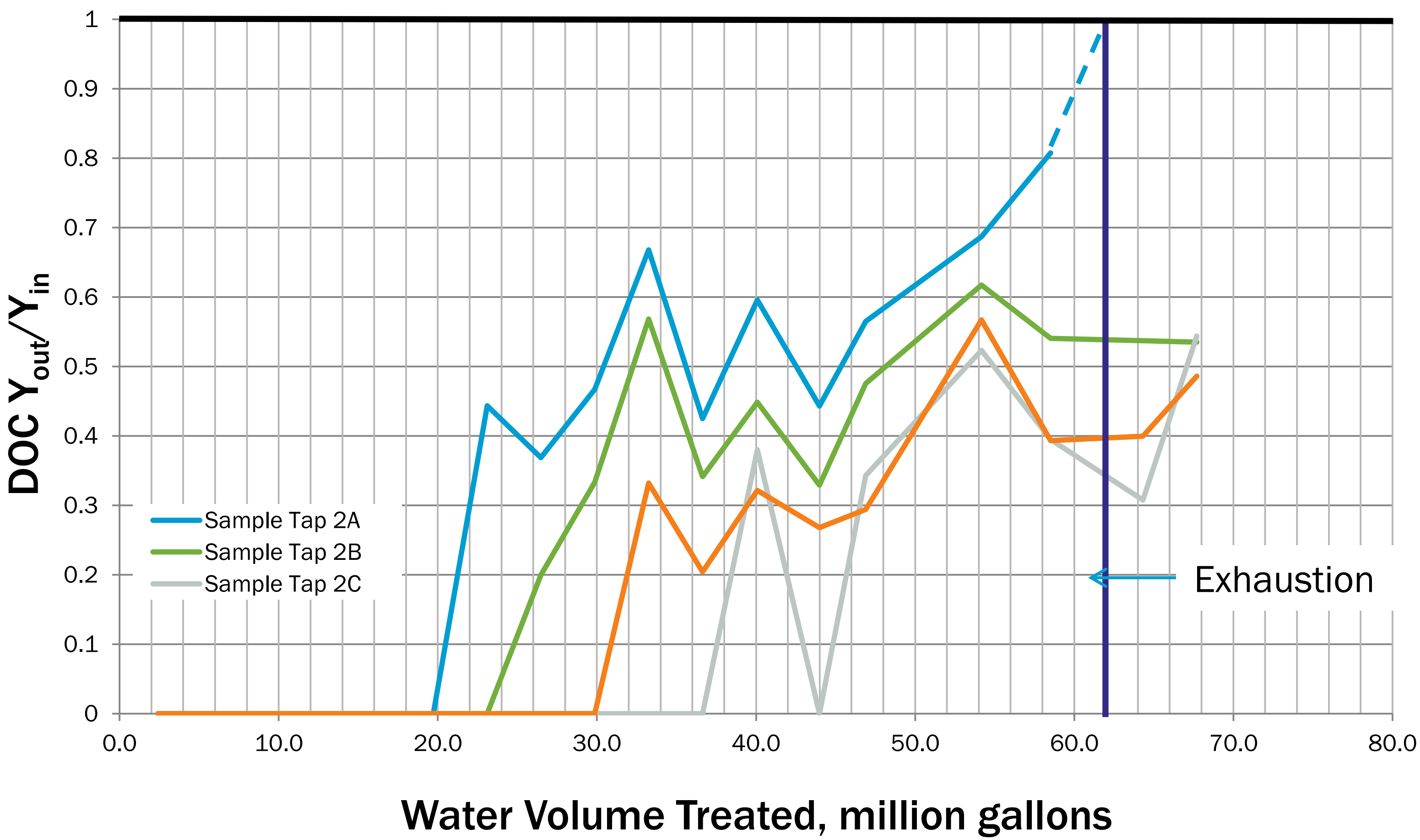
Typical Analysis

Typical Concentration Profile Across Downward Flow GAC Adsorber

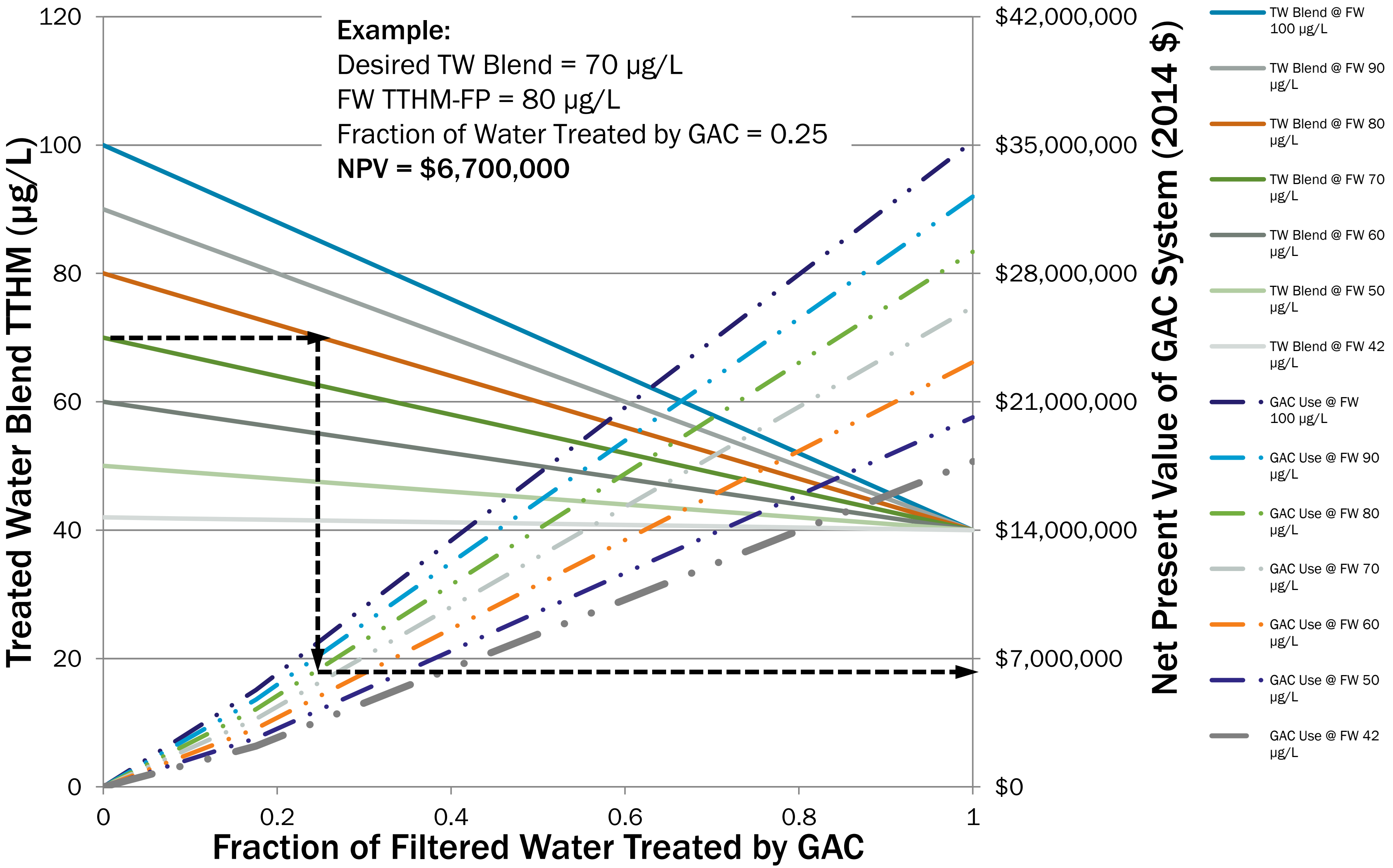


Source: Armenante, New Jersey Institute of Technology

Adsorber 2 DOC Removal and Volume Treated

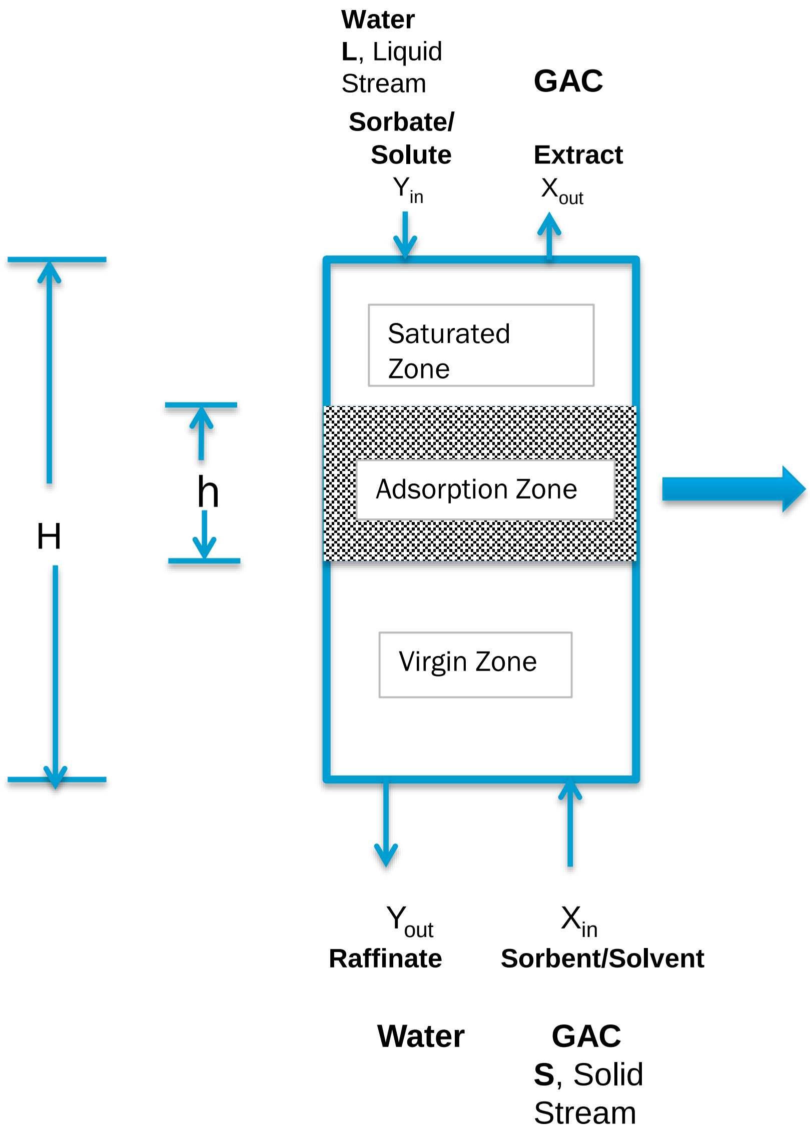


Composite Blending Nomograph

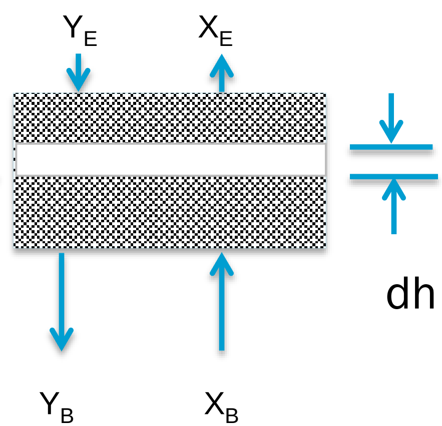


Expanded Analysis

Counter Current Mass Balance Model



DOC serves as the solute
A = Cross section area of adsorber

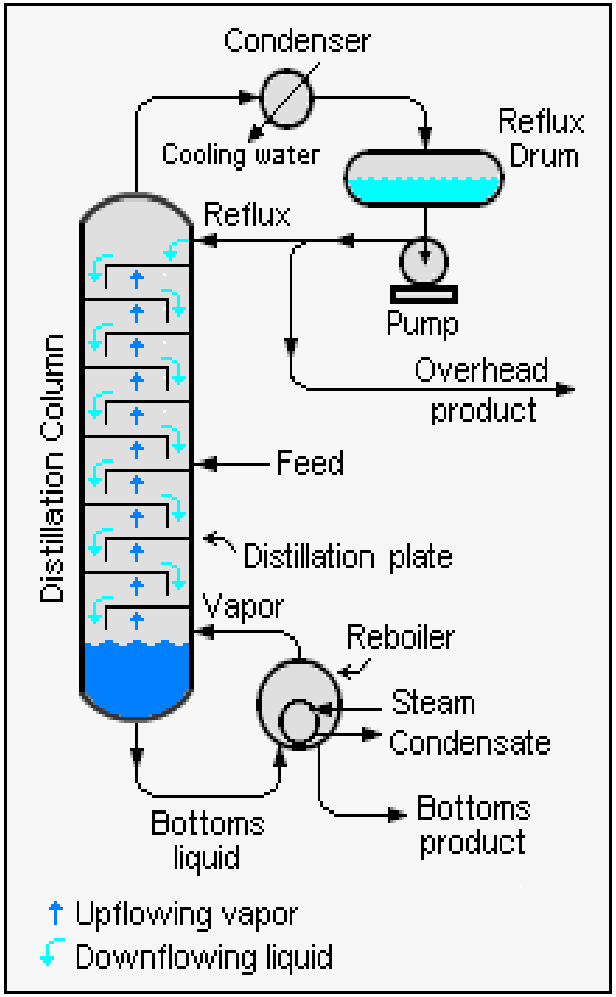


Adsorption Zone Stays Stationary and Sorbent Appears to Move!

GAC Adsorber Similar to Distillation Tower
Continuous Mass Transfer Instead of Discrete Steps

NTU:
Number
of plates

HTU:
Height
of each
plate



Mass Balance Analysis-1

- $LY_{in} + SX_{in} = LY_{out} + SX_{out}$
- S/L = slope of operating line, gm GAC/L feed water

- $(L/A)dY/dh = (S/A)dX/dh = K_La(Y_{ops}-Y_{eq})$
  - K_La – volumetric mass transfer coefficient based on liquid phase driving forces
  - Y_{eq} – equilibrium DOC concentration
- Perform Integration

  $h = L/AK_La\int dY/(Y_{ops}-Y_{eq})$, integrate from Y_B to Y_E

  NTU , number of transfer units = $\int dY/(Y_{ops}-Y_{eq})$, integrate from Y_B to Y_E

  $h = (L/AK_La)NTU$

- NTU: Solve graphically (McCabe-Thiele method) or by numerical integration

Mass Balance Analysis-2

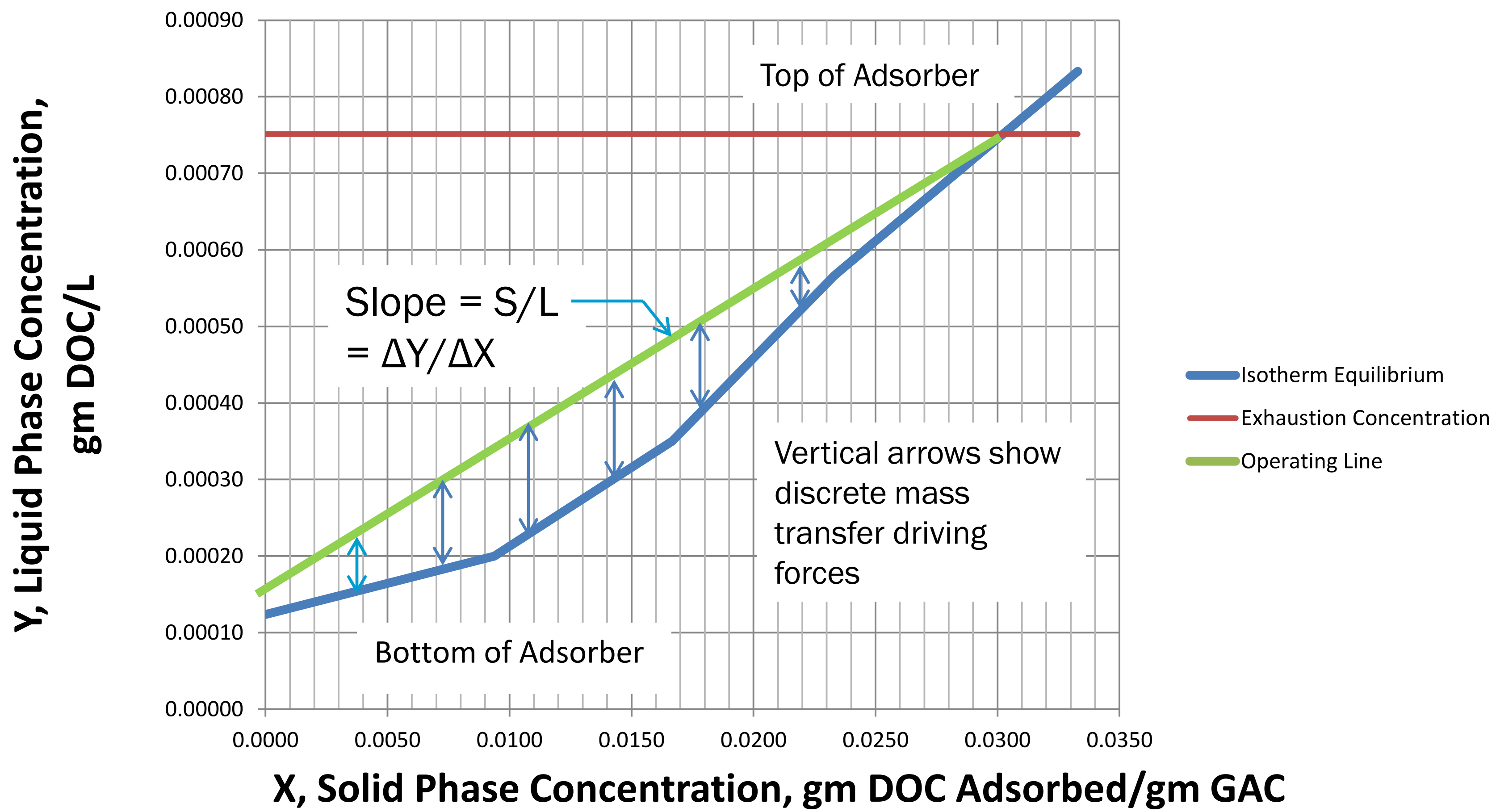
- HETP (HTU) = $L/AK_La = U_L/K_La$ U_L – liquid phase velocity
- **K_La: Liquid phase volumetric mass transfer coefficient**
- **$K_La = \alpha U_L^{0.5}$**
  - Applicable for this type of aqueous solution mass transfer
  - For this case, α is a constant
  - Diffusivity and particle size is constant

- h = HTU x NTU = height of adsorption zone

K_La is Important

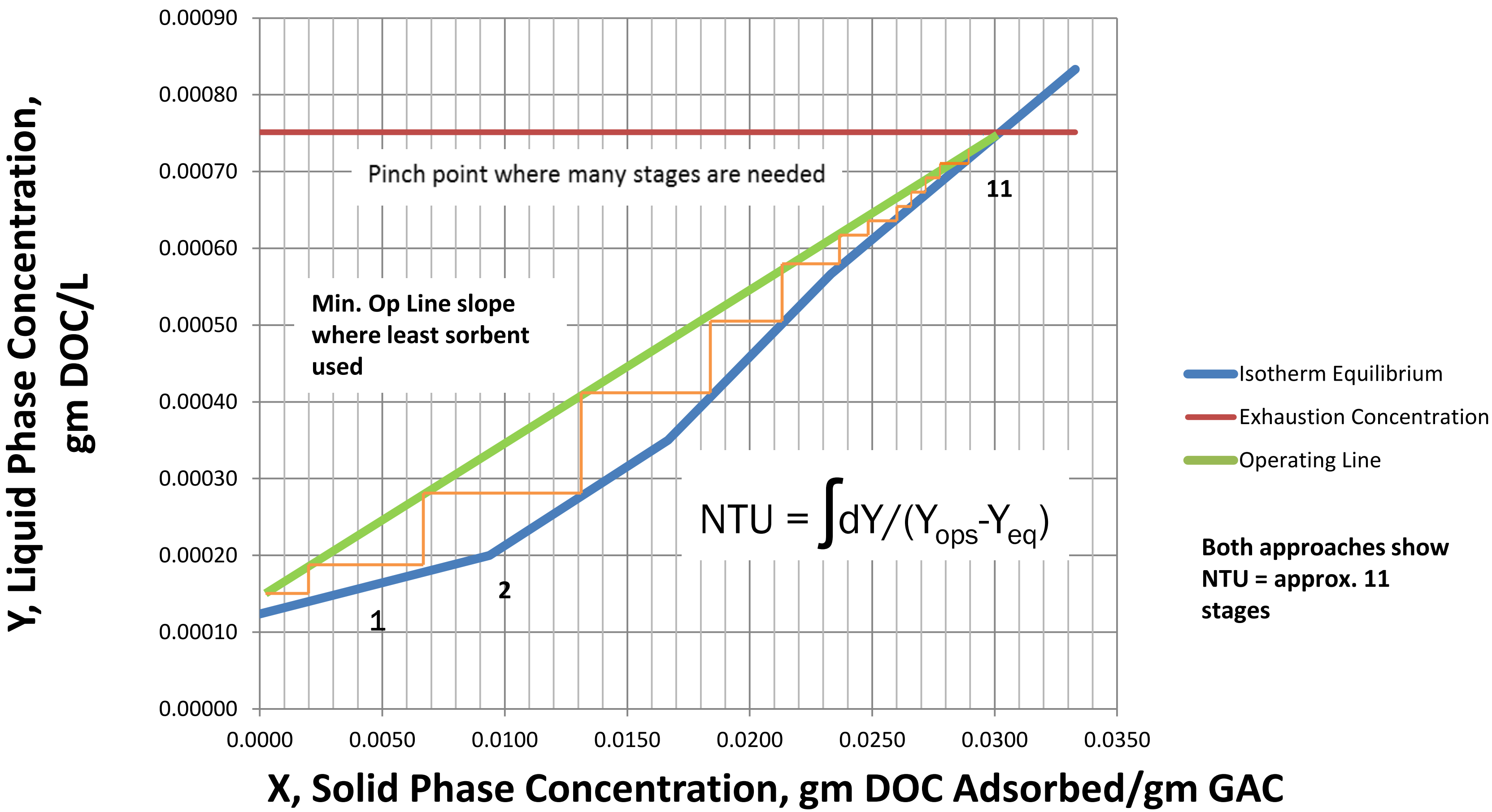
- Determined experimentally
- Useful for understanding mass transfer
- Underlying assumptions
  - Liquid phase mass transfer step is predominant
  - Other mass transfer resistances (diffusion and adsorption) are less significant
  - No chemical reaction (e.g. oxidation)
- Can investigate adsorber geometries and loading

Equilibrium and Operating Lines



2 Ways to Determine NTUs

McCabe-Thiele Graph or Numerical Integration



Both approaches show NTU = approx. 11 stages

Other Results of Mass Balance Analysis

NTU = 11.1 stages

HETP (HTU) = 14.3 cm

h, height of adsorber zone = 158 cm

U_L = 17.4 cm/min.

K_La = 1.22 min^{-1}

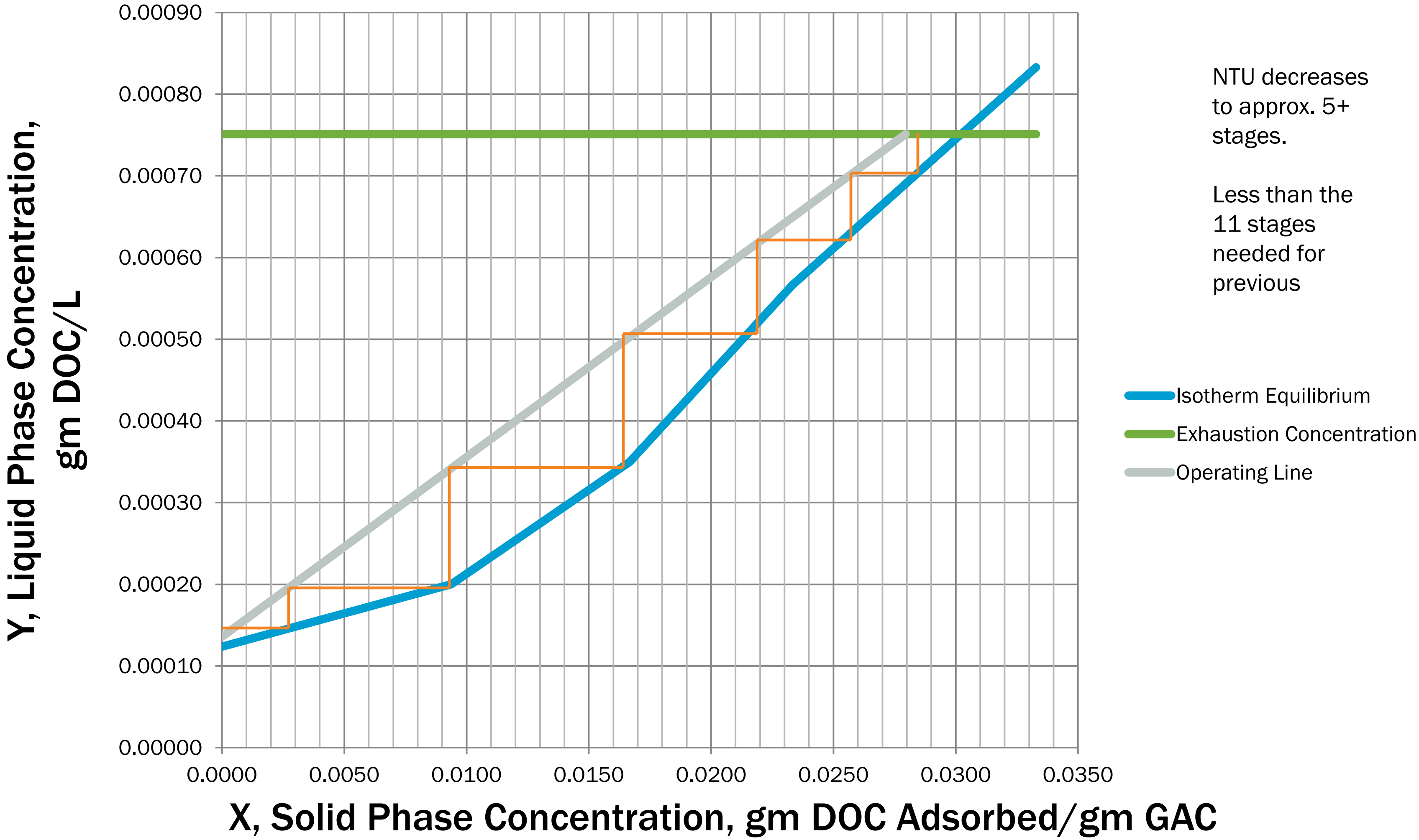
$K_La = \alpha U_L^{0.5}$

α = Experimentally calculated = 0.29 $(cm\text{-}min)^{-0.5}$

Broad and Useful Interpretations

K_La Data Allows Investigation of Other Operating Schemes for Design

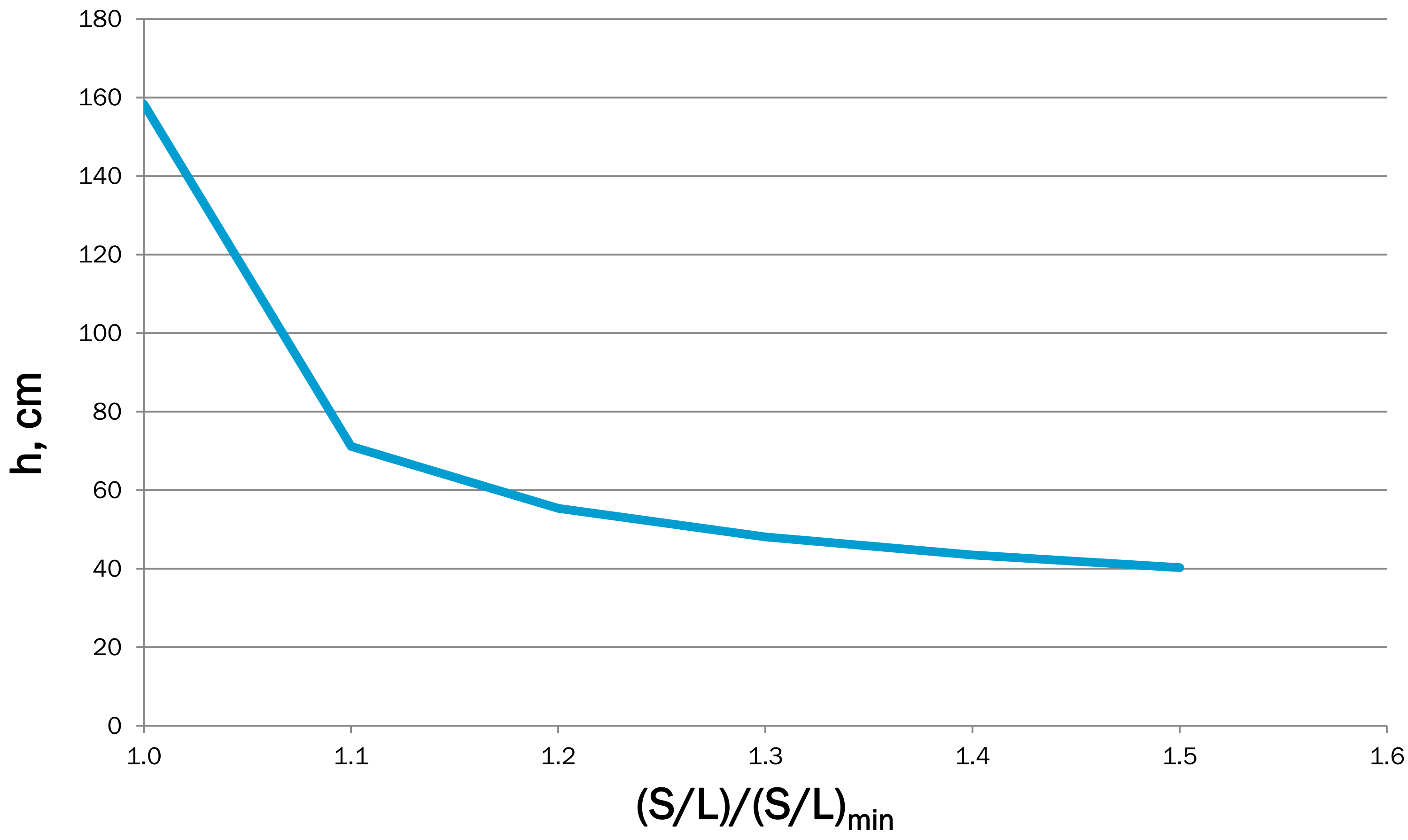
Example: Increase Op. Line Slope by 10%



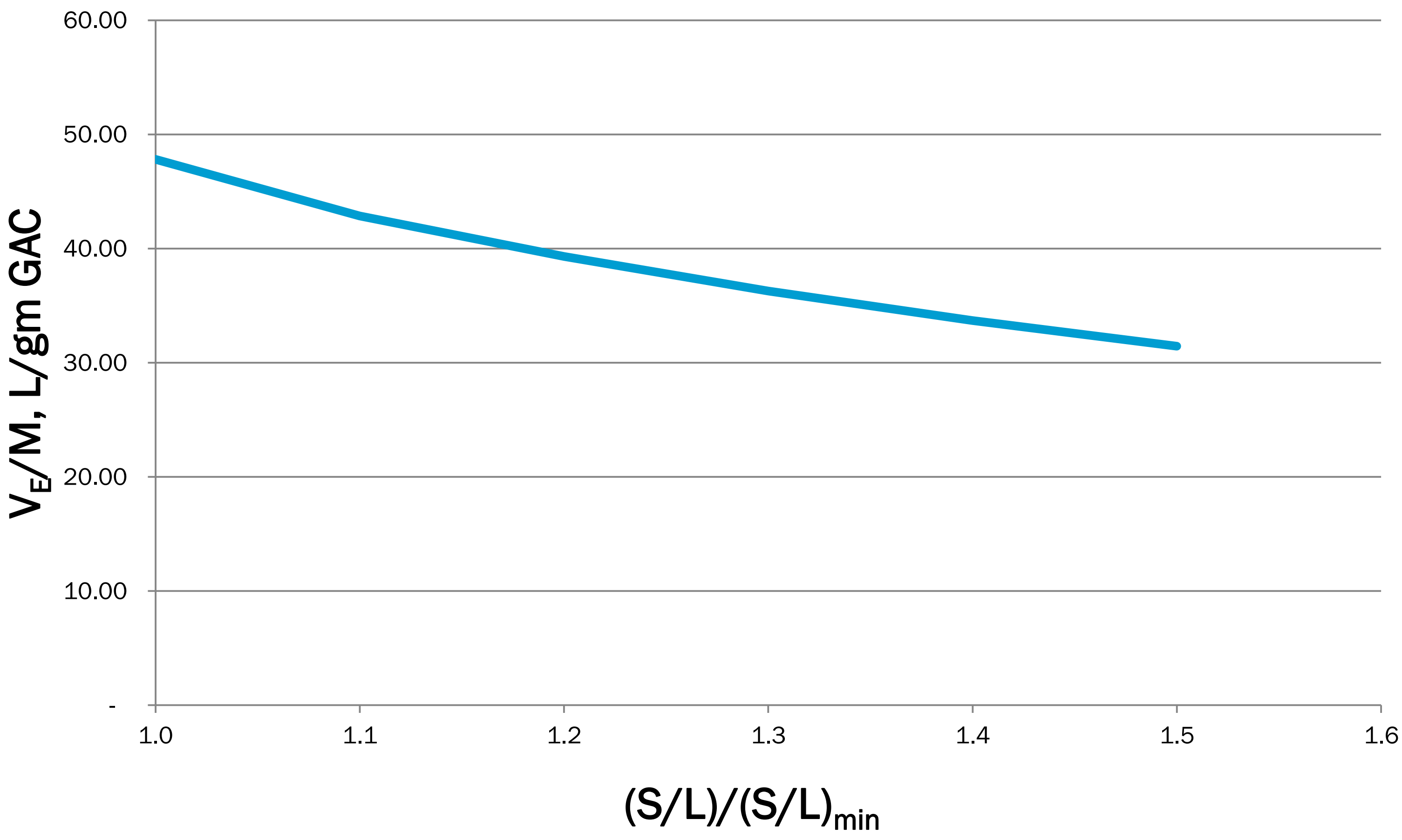
NTU decreases to approx. 5+ stages.

Less than the 11 stages needed for previous

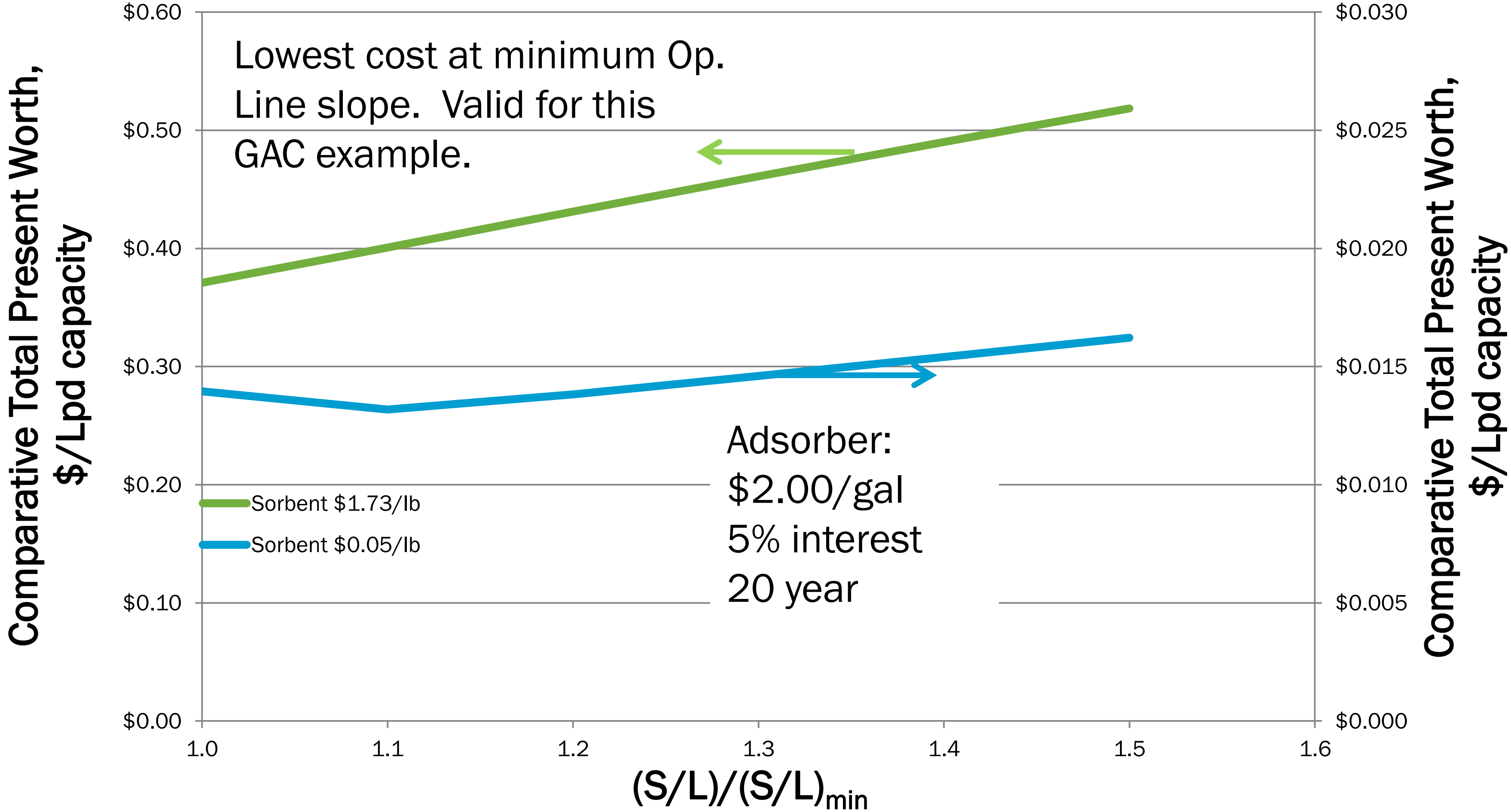
Influence of Operating Line Slope to Min. Slope on h, height of Adsorber Zone



Influence of Operating Line Slope Ratio to Raffinate Volume per Unit Mass of Sorbent Consumed



Economic Analysis of Differing Operating Line Slopes

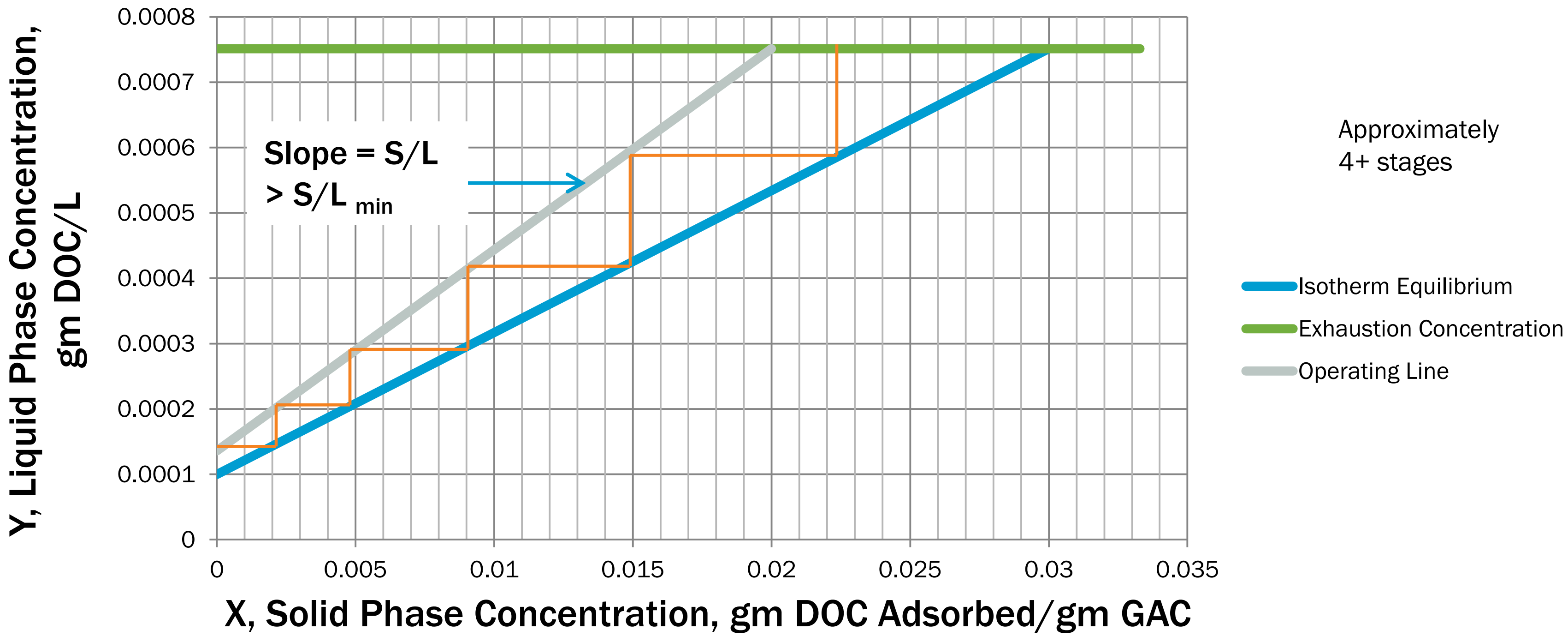


Use of Experimental $K_L a$ Determination on Design Considerations

- Permits assessment of different design parameters
  - Adsorber diameters
  - Liquid stream flow velocity
  - Number of stages
  - Adsorber height
  - Different sorbents (of similar particle size)
  - Different water quality targets
- Search for Optimal Adsorber Configuration
- **For Costly Sorbents (e.g. GAC), S/L_{min} is justified**
- For inexpensive sorbents/solvents or expensive tank construction, optimal S/L-may be larger than S/L_{min} (perhaps 1.2 to 1.4)
- Approach can be used for other related mass transfer systems
  - Ion exchange
  - Gas adsorption/stripping
- **Adjust Model and Account for Biological Oxidation!**

What to do if Results are Poor

- Less Than Favorable (Flat) Equilibrium-Poor Driving Force



- Try new sorbent
- Assess other approaches

Summary

- Mass Balance Model is Useful
- Benefits of Evaluating K_La
  - Permits Varied Design Assessments
  - Determines Optimal Design
  - Determines Optimal Operational Strategies

Questions and Discussion