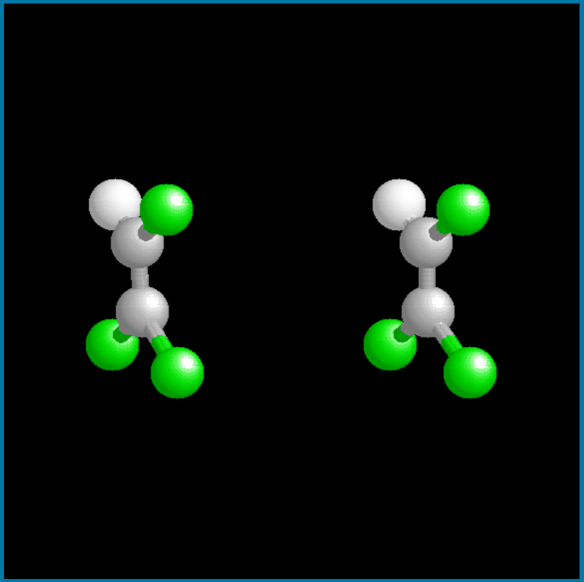
Design and Evaluation of Engineering Systems to Remove VOCs From Groundwater

IPRO 296/496-304B
Spring 2003

Problem Statement

- *Desired clean up of trichloroethylene (TCE) from groundwater at Wurtsmith AFB located in Oscoda, Michigan*
- *Investigate the most cost-effective and reliable treatment technology at full-scale performance*
  - *minimizes energy requirements*
  - *costs associated with the construction and operation of various control systems*

Background



- Trichloroethylene
  - C_2HCl_3 (131.30 g/mole.)
  - Removes grease from metal parts
  - Found in adhesives, spot removers, and typewriter correction fluid
- Drinking or breathing high levels of trichloroethylene may cause nervous system effects, liver and lung damage, abnormal heartbeat, coma, and possibly death.
- Reason for proper disposal and remediation

Requirements

- *95% removal of TCE*
- *Other removal efficiencies based on the drinking water regulations*
- *Drinking water standards for TCE vary from 1.5 µg/l to 5 µg/l in individual states*
    - *Michigan's discharge limit: 1.5 µg/l*

Methodology

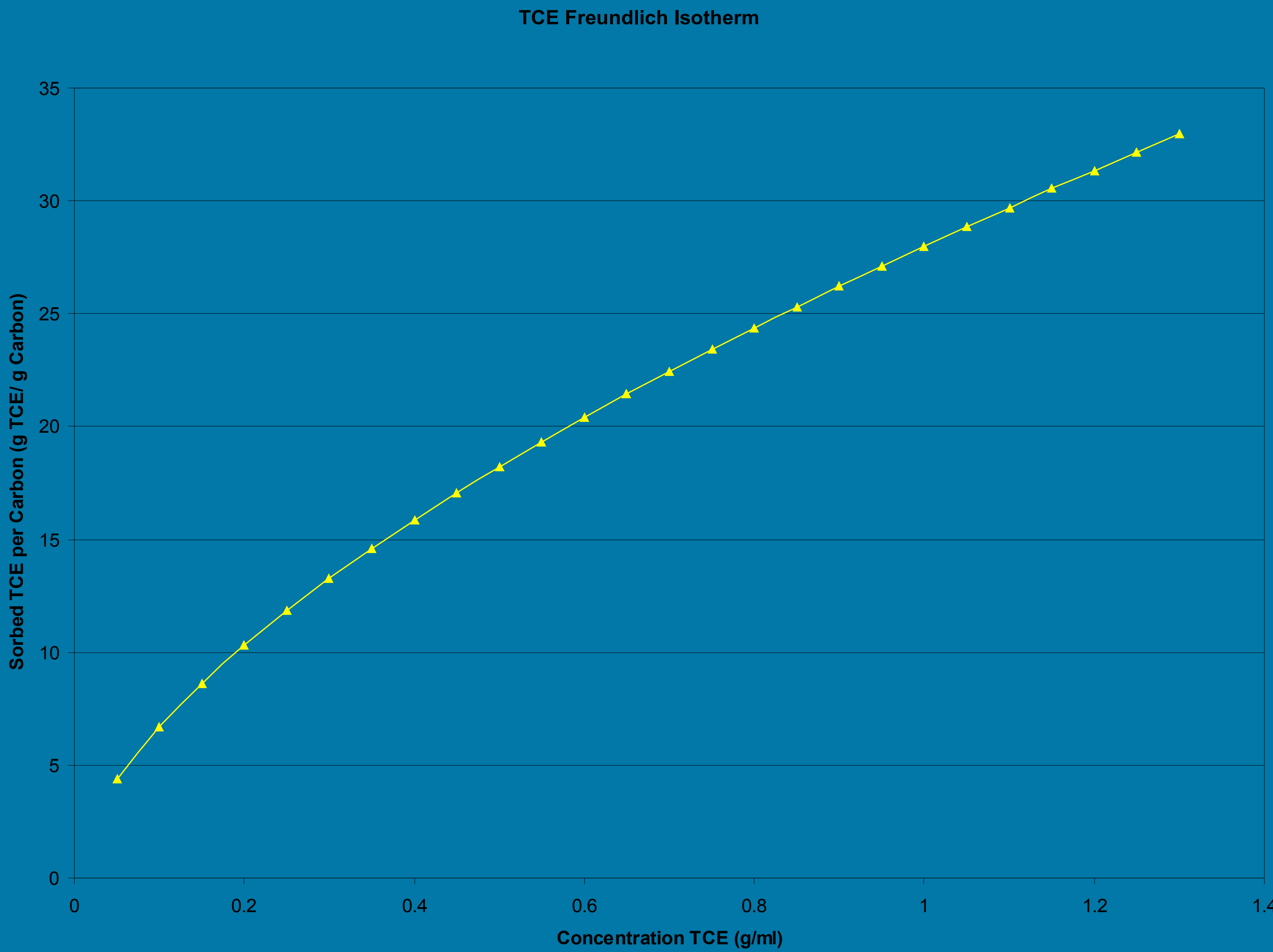
- *Ion exchange*
- *Membrane separation*
- *Biological treatment*
- *Oxidation*
- *Distillation*
- *Phytotremediation*

Carbon Sorption and Air Stripping

Carbon Sorption Design

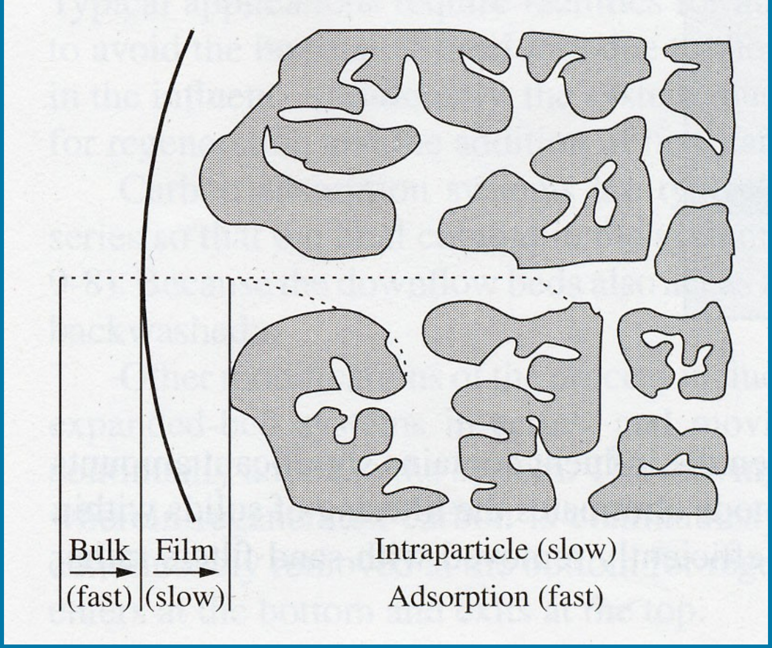
- *Carbon sorption operates on equilibrium equations between liquid and solid phases*
- *The governing mole balance equation is an empirical equation known as the Freundlich isotherm*

Freundlich Isotherm



Physical Process

- Water passes through granular activated carbon (GAC)
- TCE binds to GAC surface up to saturation
- Carbon is then thermally regenerated or replaced



GAC is a processed material with a very high surface to volume ratio

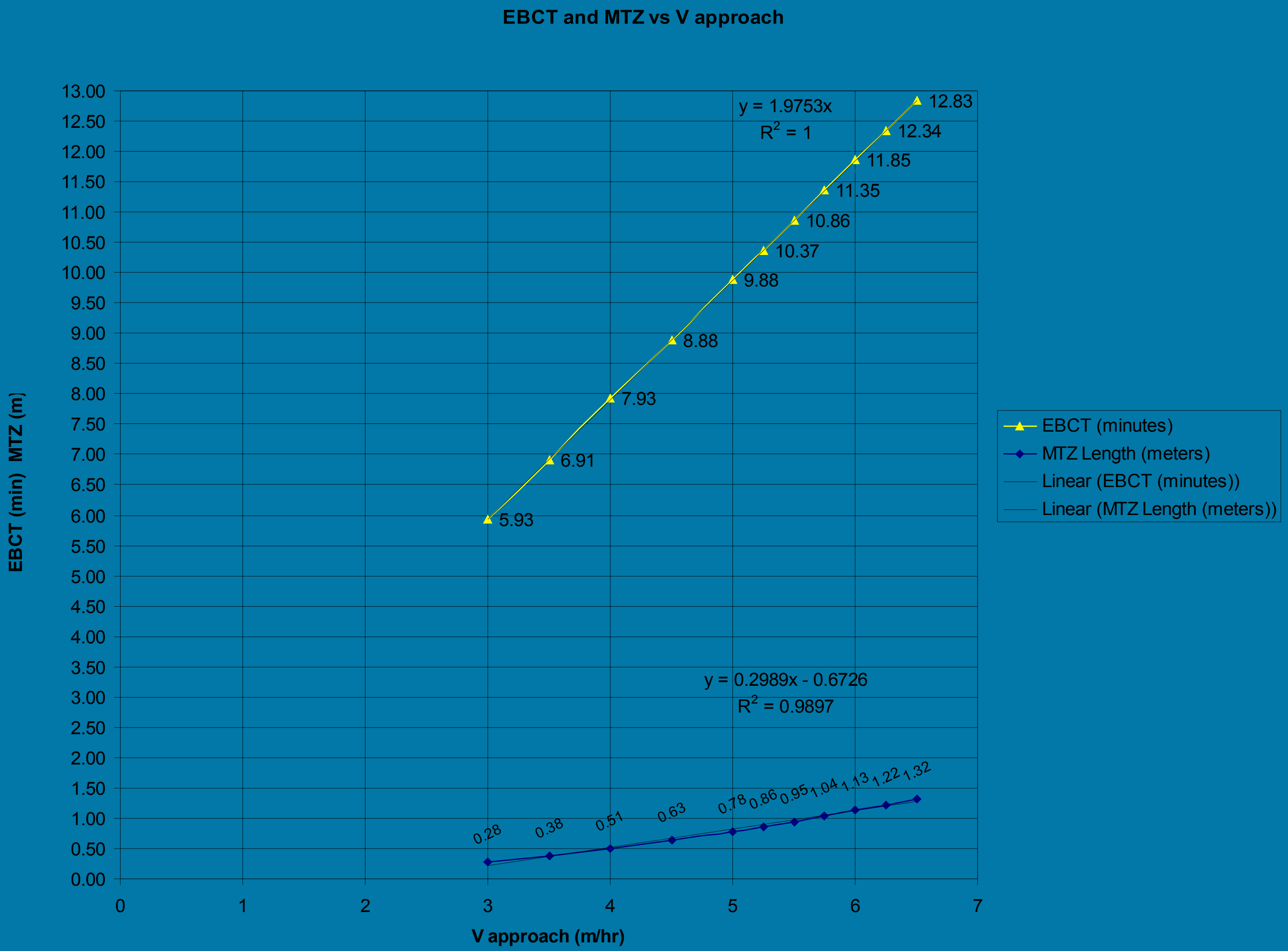
Design Method

- *System with large flow rate (4500 L/min)*
- *Achieved by empirical equations*
  - *Summers*
  - *Snoyienk*
  - *Eckenfelder*
- *MTZ: mass transfer zone*
- *EBCT: empty bed contact time*

Design

- *MTZ and EBCT are a function of the approach velocity*
- *Approach velocity is a function of the volume of flow, a constant in our case, and of the total cross-sectional area of the carbon sorption units*
- *Pressure drop constraint 18 inches H_20 per bed due to potential GAC crushing*

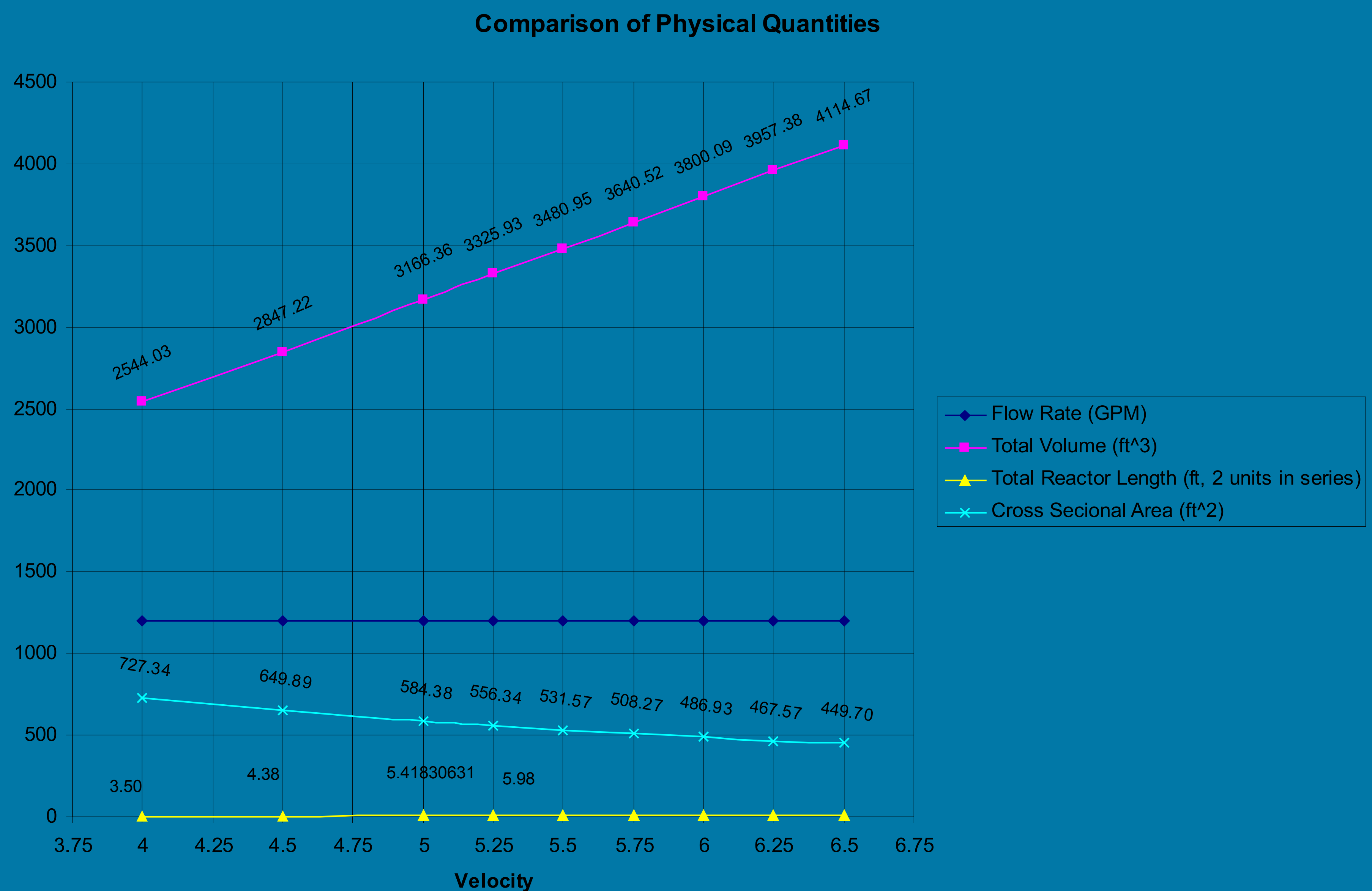
Estimates of MTZ and EBCT



Physical Parameters

- Approach velocity and total cross-sectional area as controlling variables for the system physical parameters:
  - bed volume
  - bed length
  - total overall length
  - pressure drop

Physical Parameters



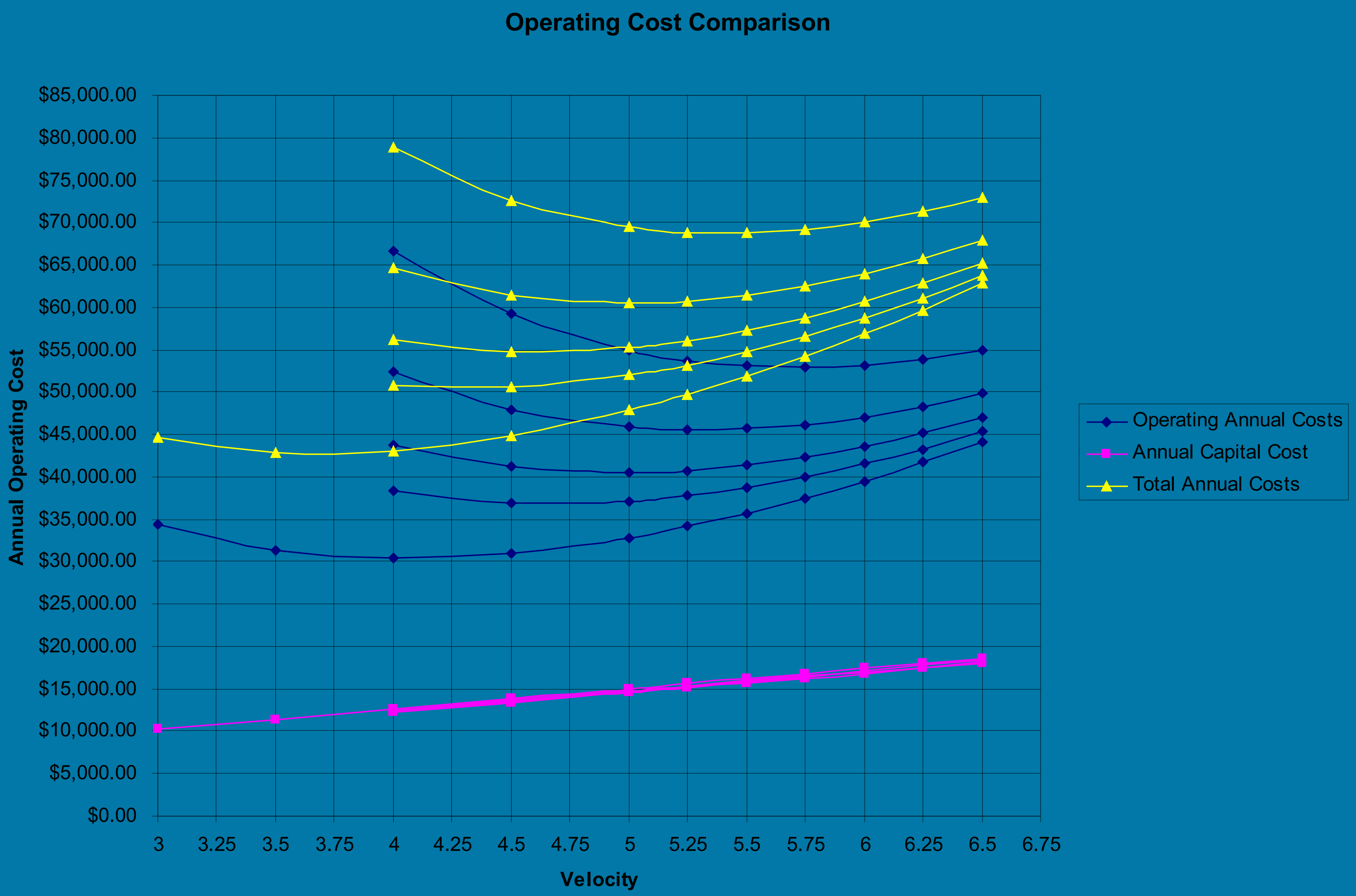
Costing of Carbon Sorption

- Costing models provided by EPA
- Costing variables: volume and flow rate
- Volume and flow rate are directly related to design variables

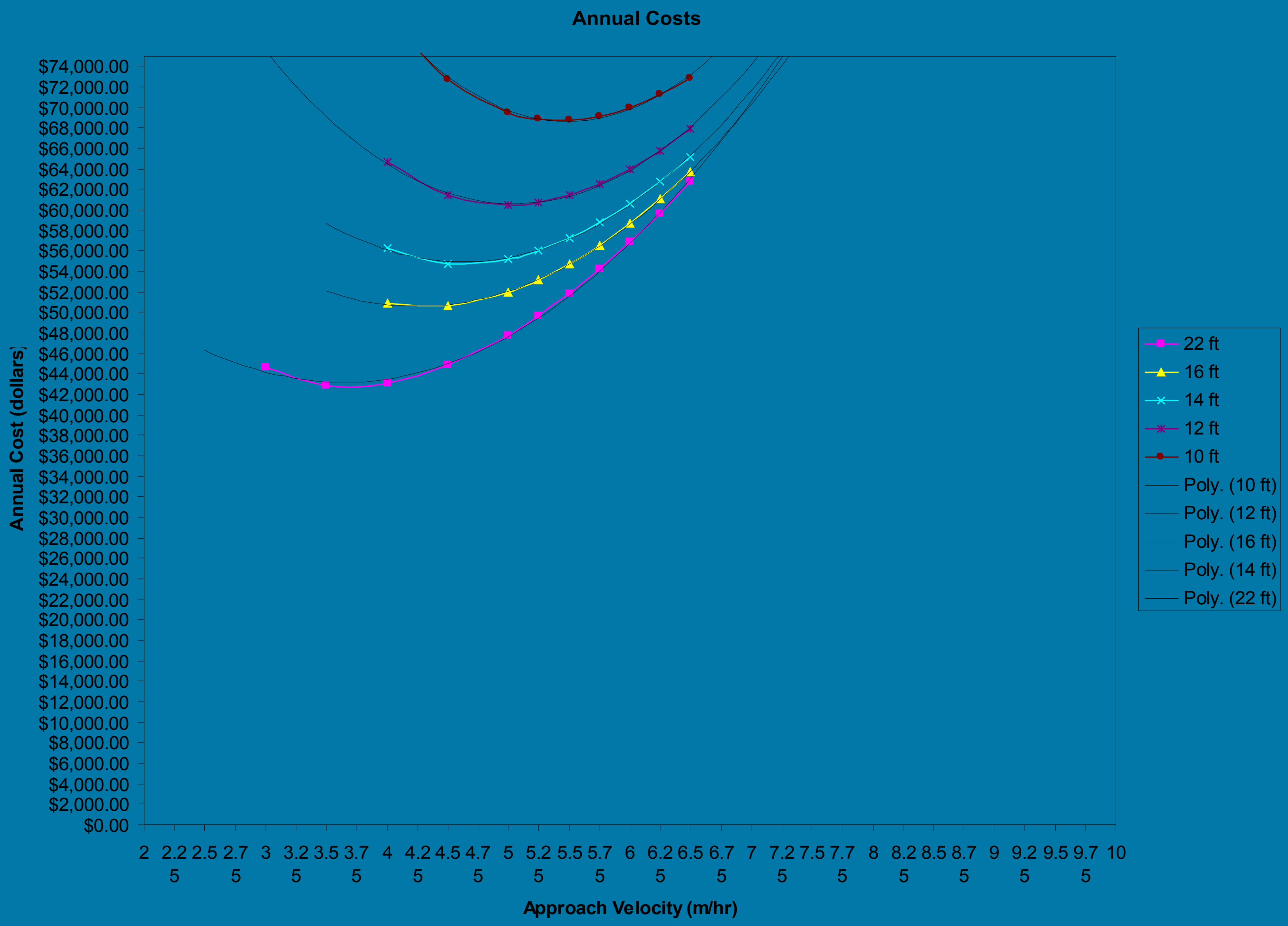
Trends

- *Lower approach velocity leads to lower capital costs and electricity costs*
- *Operating costs are a function of two opposite variables: frequency of carbon changes and bed volume*
- *End result: Costing curves highly sensitive to changes in approach velocity*

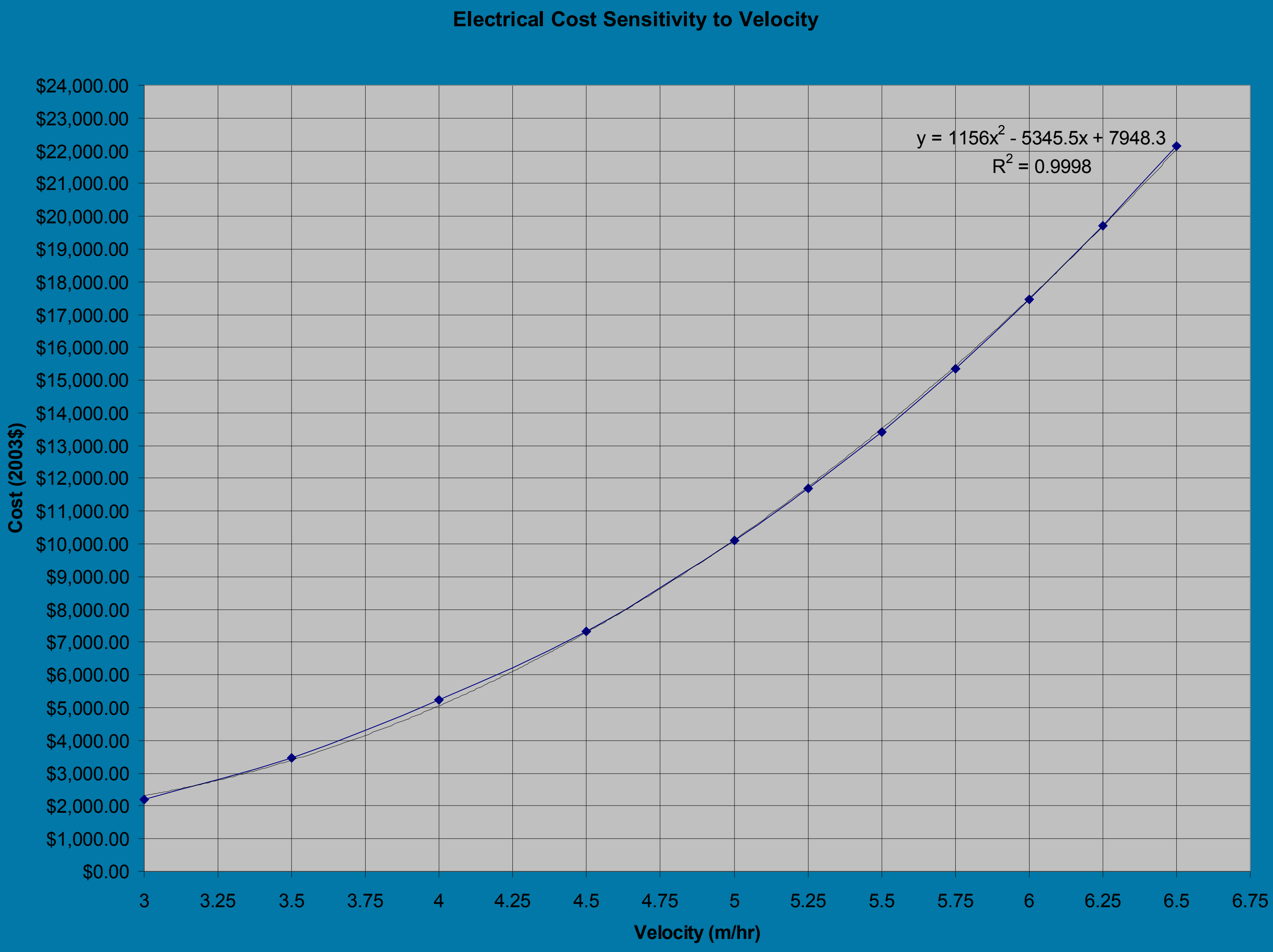
Cost Comparison



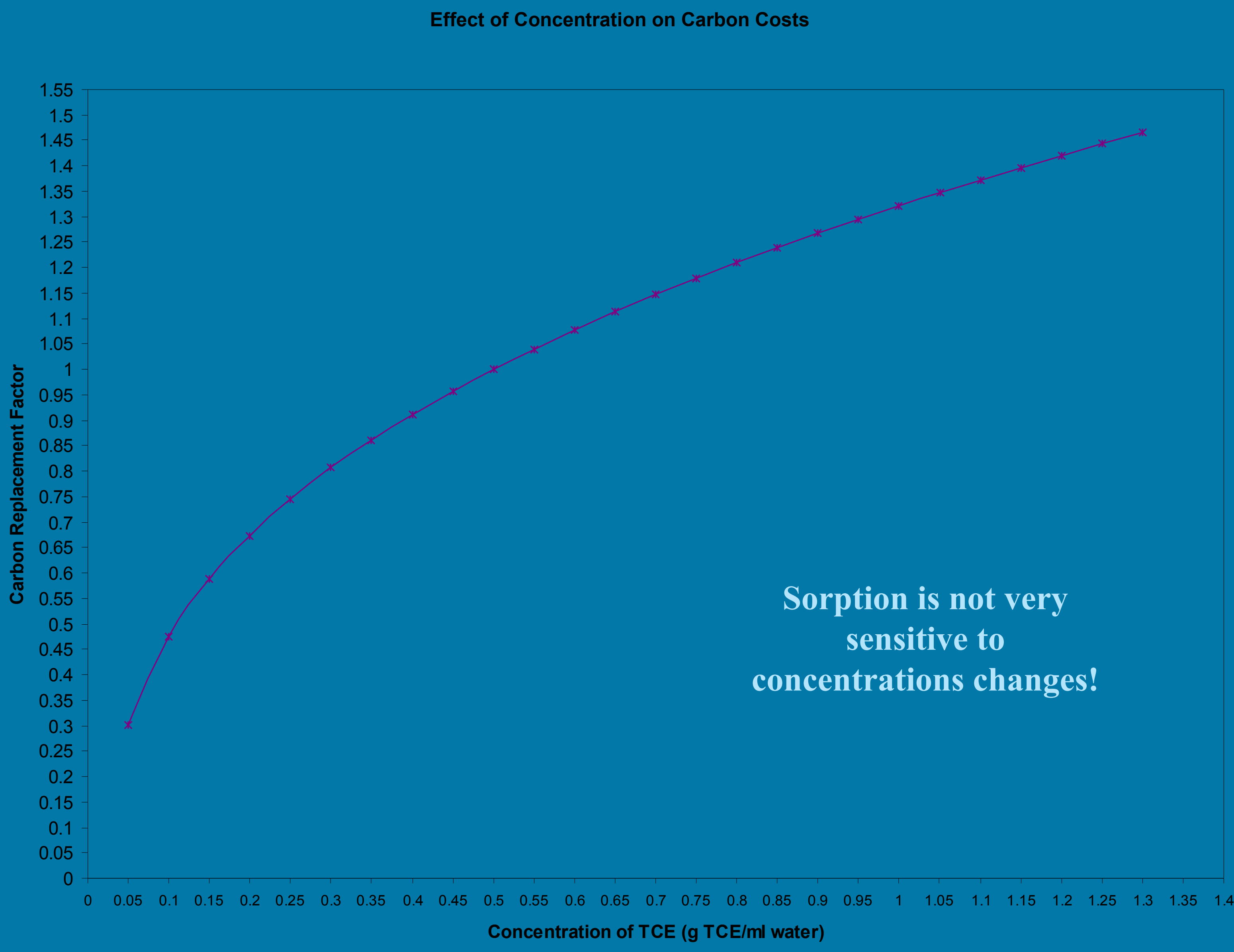
Overall Costing Curves



Electrical Cost



Cost Sensitivity to Concentration



Two Design Options

- ***Aggressive***
  - *$42,000/year*
  - *2 cylindrical units in series*
  - *22 ft diameter*
  - *MTZ 0.45 m*
  - *EBCT 7.8 minutes*
  - *Velocity 3.25 m/hr*

vs.

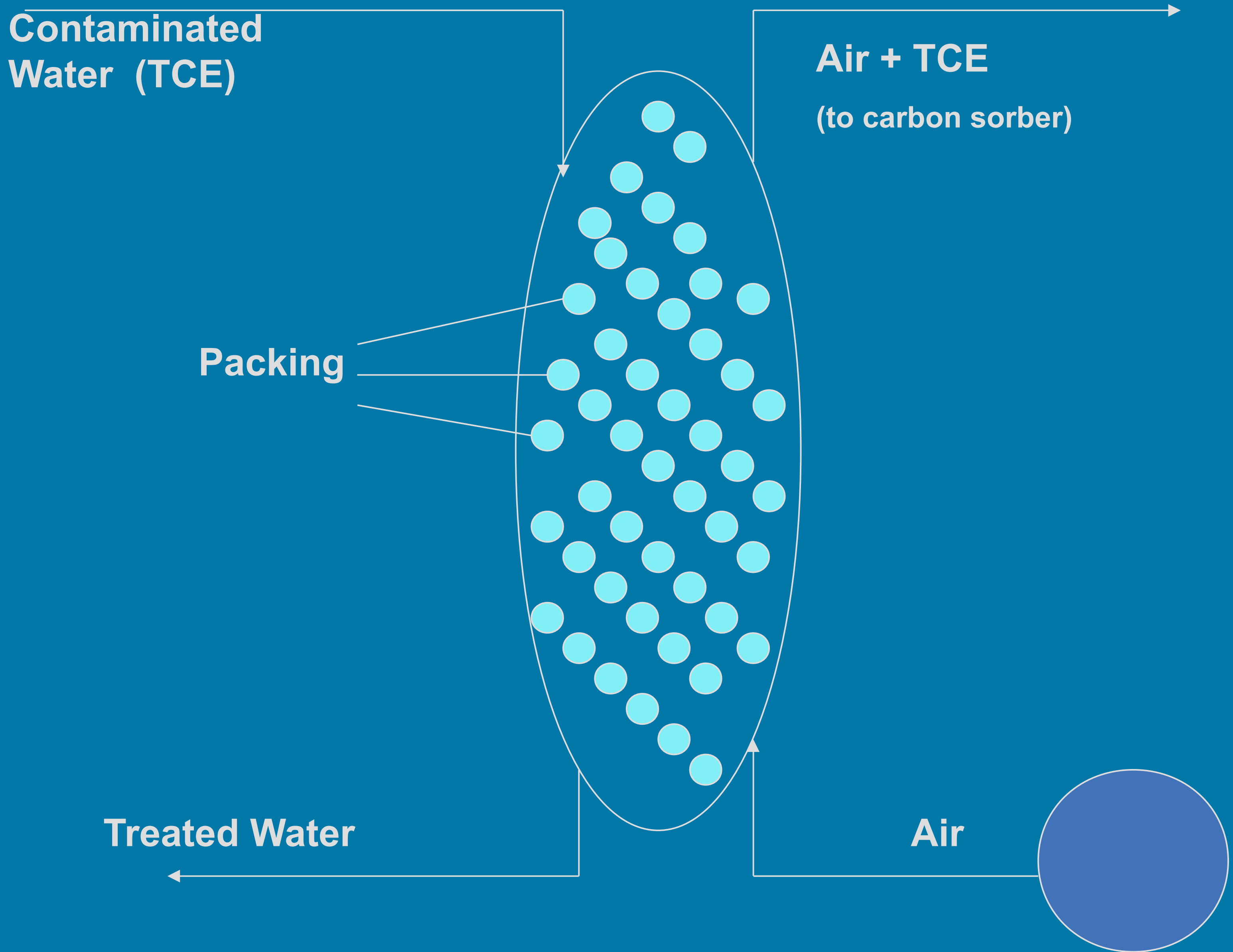
- ***Conservative***
  - *$50,000/year*
  - *2X2 (2 units parallel/ 2 units in series)*
  - *14 ft diameter*
  - *MTZ 0.85 m*
  - *EBCT 9.88 minutes*
  - *Velocity 5 m/hr*

Advantages and Limitations

- Robust, well studied concept
- Few operating parts
- Easy adaptation to concentration levels
- Has already met Michigan regulations at this very site

- Isothermal operation
- Interfering organic compounds
- Low or high pH
- Offsite carbon regeneration

Stripper Basics



Mass Transfer Coefficient (K_La)

$$\frac{1}{K_La} = \frac{1}{H'k_ga} + \frac{1}{k_La}$$

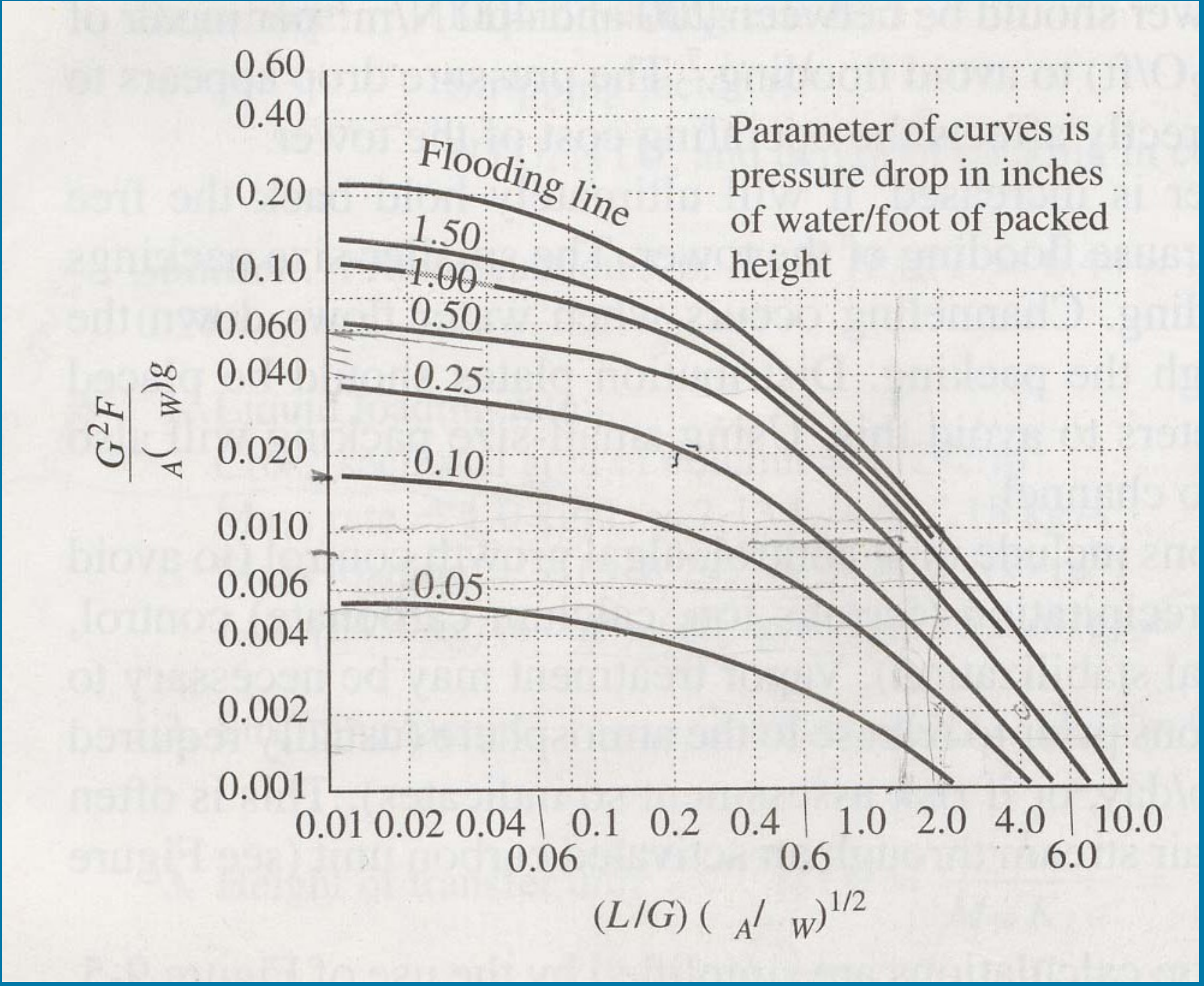
- *H', k_g, k_L, and a are determined with fluid properties (density, viscosity, etc.) and dimensionless quantities (Reynolds Number, etc.)*
- *This quantity is critical to find the correct packed bed volume*

Packed Bed Volume

$$V = Z * A = L\left(\frac{\ln[\frac{c1}{c2} - \frac{LRTa}{GH}\left(\frac{c1}{c2} - 1\right)}{KLa\left(1 - \frac{LRTa}{GH}\right)}\right)$$

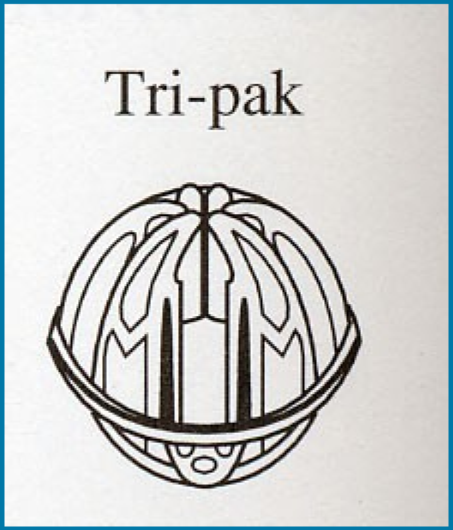
- *G/L is the gas to liquid ratio, critical for optimization*
- *Note the mass transfer coefficient in the denominator*
- *c1 and c2 denote inlet and outlet concentrations of TCE in the water*

Pressure Drop



Packing

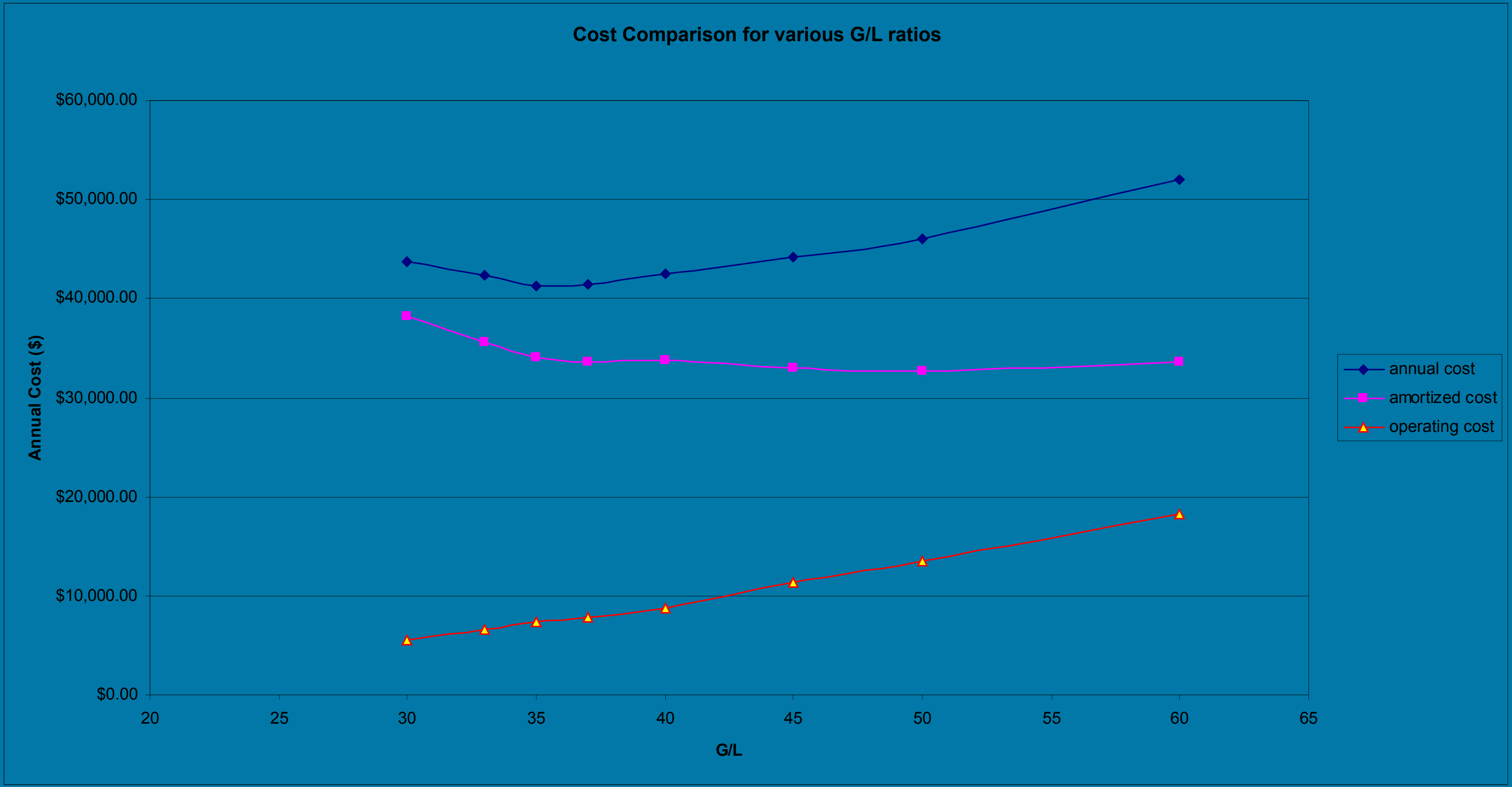
- *State of the art Tri-Pak Packing to be used*
- *Bigger packing needed due to large inlet flow*
- *12:1 optimum diameter ratio (tank - packing)*
- *Mass Transfer coefficient and pressure drop dependent on packing choice*



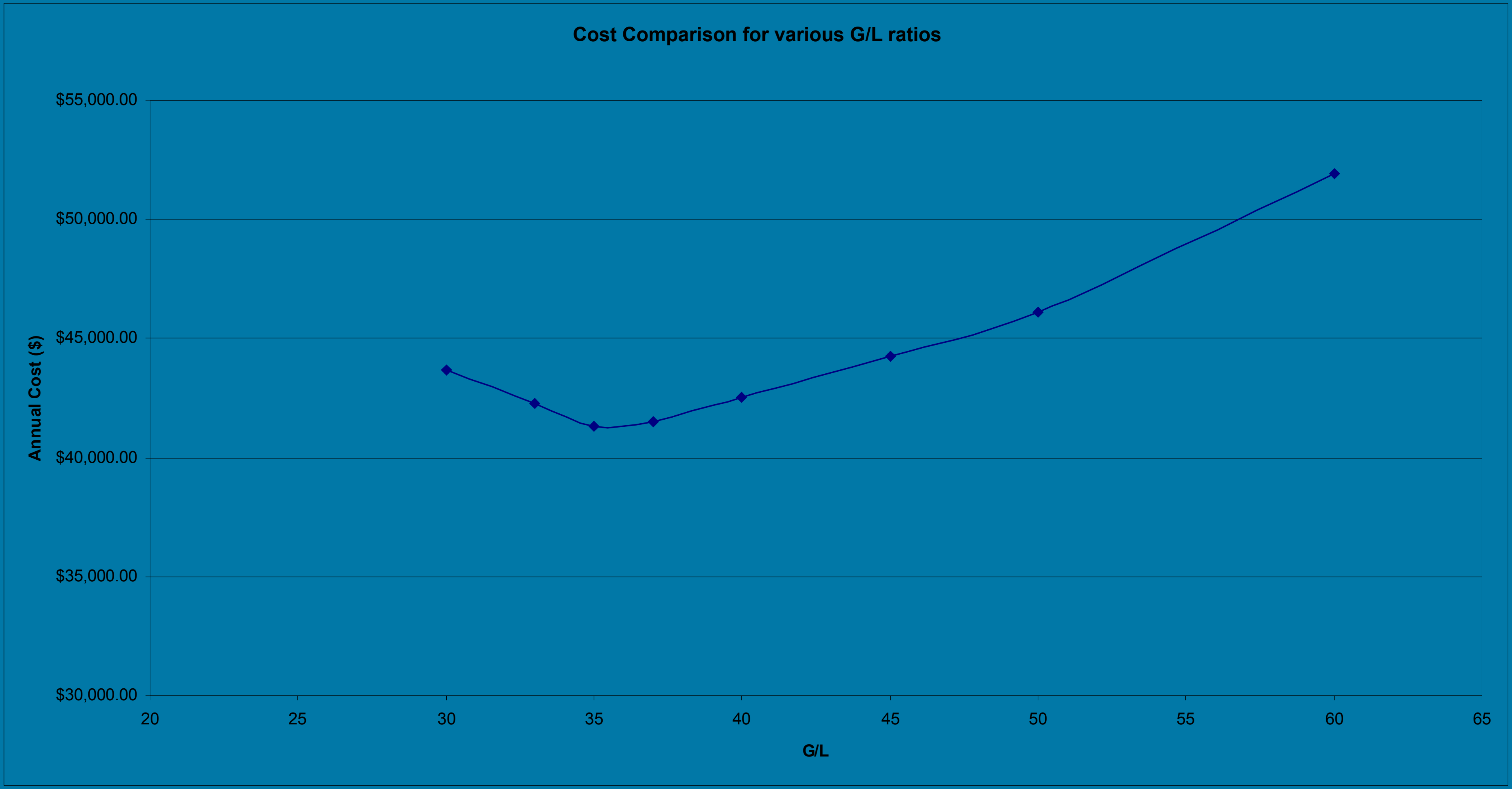
Air Stripper Cost Estimate

- Capital costs estimated
  using Ulrich's costing charts (1984)
- Amortized at 10% over 15 years
- Operating costs based on power requirements calculated using HYSYS
- Electricity rate for Oscoda, MI: $0.08235/kWh
- Costs compared as function of G/L ratio

Functional Cost Comparison



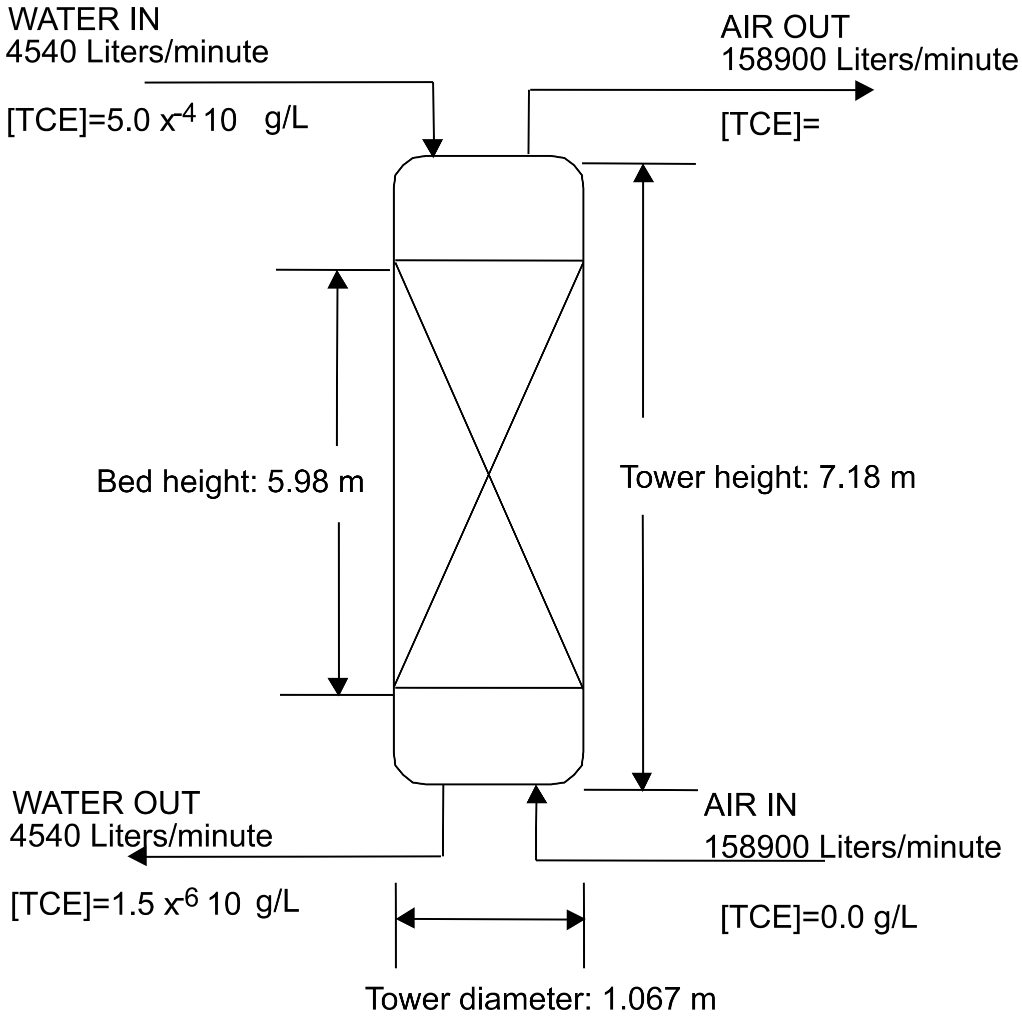
Cost Comparison



Functional Cost Comparison

Capital cost for vessel	**G/L**	30	33	35	37	40	45	50	60
Diameter (m)		1.0668	1.0668	1.0668	1.0668	1.0668	1.0668	1.0668	1.0668
Height (m)		7.59	7.3266	7.1796	7.05	6.88	6.6558	6.48	6.21
Pressure (barg)		0.0258	0.0274	0.0283	0.0288	0.03	0.0344	0.037	0.0423
Material factor		1	1	1	1	1	1	1	1
CBM (2 tanks)		157,500.00	144,000.00	135,000.00	130,500.00	127,800.00	121,500.00	117,000.00	108,000.00
Inflation adjusted		197,777.87	180,825.48	169,523.89	163,873.09	160,482.61	152,571.50	146,920.70	135,619.11
Blower CBM		14,000.00	15,500.00	17,000.00	19,750.00	22,750.00	25,625.00	28,750.00	42,500.00
Inflation adjusted		17,580.25	19,463.85	21,347.45	24,800.72	28,567.91	32,178.14	36,102.31	53,368.63
Pump CBM		10,000.00	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00	10,000.00
Packing material	356.68	4032.124728	3893.1622	3815.04928	3746.21004	3657.111376	3536.4822	3441.355644	3299.753684
Total CBM		229,390.25	214,182.49	204,686.39	202,420.02	202,707.64	198,286.12	196,464.37	202,287.49
CTDC		$263,798.78	$246,309.87	$235,389.34	$232,783.02	$233,113.78	$228,029.04	$225,934.02	$232,630.62
CTPI		$290,178.66	$270,940.85	$258,928.28	$256,061.32	$256,425.16	$250,831.95	$248,527.42	$255,893.68
Operating Costs									
Compressor		5,375.45	6,471.74	7,085.65	7,620.51	8,575.25	11,031.93	13,162.96	17,999.22
Pump		185.31	196.81	203.36	206.76	215.48	247.08	265.75	303.73
Annual operating cost		5,560.75	6,668.54	7,289.01	7,827.28	8,790.73	11,279.01	13,428.70	18,302.95
Amortized capital		$38,151.28	$35,621.99	$34,042.63	$33,665.70	$33,713.54	$32,978.17	$32,675.18	$33,643.66
Annual cost		$43,712.04	$42,290.53	$41,331.65	$41,492.98	$42,504.27	$44,257.18	$46,103.88	$51,946.61
	G/L	30	33	35	37	40	45	50	60

Final Stripper Design



Conclusion

- Carbon Sorption vs. Air Stripping
  - Tough competition
- Most cost-effective design is the Air Stripping Column
- Do Not Pollute, saves $$$!!!

Accomplishments of Senior Team Members

- *Research of unit operations*
- *Design of unit operations*
- *Costing of chosen designs*
- *Working together with sophomore team members*
- *Utilizing everyone's knowledge to accomplish a common goal*

Accomplishments of Sophomore Team Members

- *Working with a team that involves delegation of tasks*
- *Apply classroom material to real-life situations*
- *Learning more about different unit operations and design process*
- *Cost estimation*
- *IPRO process as a whole*

Acknowledgements

- Dr. Kenneth E. Noll
- Professor J. Abbasian

The End

Any Questions???