VAPOUR INTRUSION Understanding Diffusion – The Often Overlooked Pathway

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SMART Remediation
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VAPOUR INTRUSION
Understanding Diffusion – The Often Overlooked Pathway

January 2019

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Introduction

What is Diffusion?

For vapour intrusion control membranes, it is simply defined as:

"Movement of gas or vapor from regions of high concentration (or high vapor pressure) toward regions of lower concentration".

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Introduction

Examples of Diffusion

- Helium Balloon
- Gasoline in Plastic Pop Bottle

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Fick's Law of Diffusion

"Flow of gas/vapour goes from regions of high concentration to regions of low concentration, with a magnitude proportional to the concentration gradient"

Rate of Flux = (Conc. difference) x Area x D/(thickness)

Where, D is diffusion coefficient of membrane

Thickness = membrane thickness

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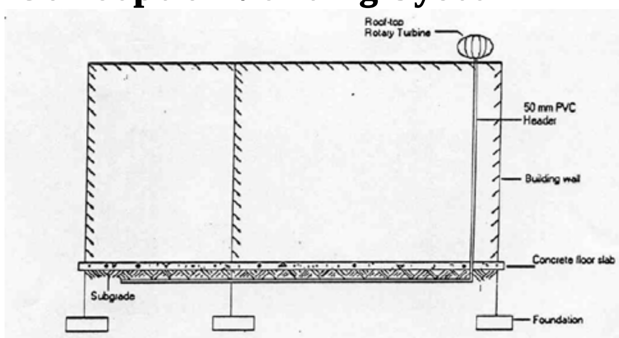
Why Does Diffusion Matter?

Concept of Venting System



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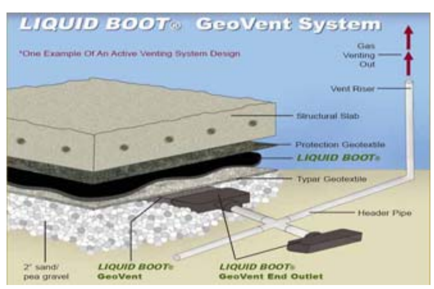
Why Does Diffusion Matter?

Myth of the "Impermeable" Membrane



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CASE STUDY: Risk Assessed Commercial Devt Site in Guelph Area

-10,000 sf Slab-on-Grade Building

-Seated on Sand and Gravel Aquifer

-Groundwater Table at 1 m bgs

-Contaminants of concern: CVOCs in groundwater, primarily TCE and it degradation compounds

-TCE concentration max 2.2 μg/L or 2.2 ppb

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CASE STUDY: Risk Assessed Commercial Devt Site in Guelph Area

LEVEL 2 RISK MANAGEMENT MEASURES:

- Subslab Mitigation System:

Composite of CUPOLEX® blocks, underlain by Liquid Boot®, in conjunction with a passive venting system known as Geovent® with header to roof

- Air Monitoring Program: SUMMA canister tests

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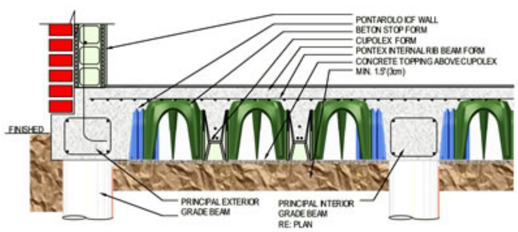
CASE STUDY: Risk Assessed Commercial Devt Site in Guelph Area

Concept of CUPOLEX® System:



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CASE STUDY: Guelph Commercial Devt Site:

CUPOLEX® Blocks

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CASE STUDY: Guelph Commercial Devt Site:
Installation of Geovent® & Header System

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CASE STUDY: Guelph Commercial Site:
Carrier Geotextile Laid for Liquid Boot®

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CASE STUDY: Guelph Commercial Devt Site:
Liquid Boot® Spray-Applied

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CASE STUDY: Guelph Commercial Site:
Smoke Testing Underway

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CASE STUDY: Guelph Commercial Devt Site:
Concrete Slab Pour Completed

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CASE STUDY: Guelph Commercial Site:
Air Monitoring Program

Initially, Indoor Air Monitoring was rejected by Tenant whose work force was unionized and was afraid of perceptions of hazard.

Instead, it was proposed to conduct air monitoring indirectly within the CUPOLEX® layer.

However, results of air monitoring showed exceedences of TCE and derivatives above the provincial draft Health-Based Indoor Air Quality Criteria (HBIAC, 2013) in *the CUPOLEX® layer*.

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CASE STUDY: Guelph Commercial Site:

Subslab Air Monitoring Port - North

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CASE STUDY: Guelph Commercial Site:

Subslab Air Monitoring Port - South

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CASE STUDY: Guelph Commercial Site:
Evacuation of SubSlab under CUPOLEX®

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CASE STUDY: Guelph Commercial Site:
Air Monitoring Program

Therefore, a more comprehensive program of air monthly monitoring was conducted as follows:

- North and South Ports within the CUPOLEX® Layer;
- Geovent® stack connected to exhaust conduit
- Indoor in open/warehouse part of building
- Ambient outdoor location

Voluminous data was compiled.

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CASE STUDY: Guelph Commercial Site: Air Monitoring Program

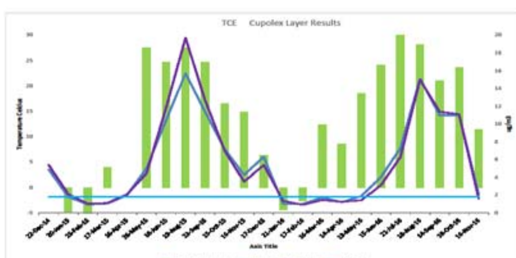
Summary of Air Monitoring Results: Building B, Guelph

16-Dec-16

Parameters / Analysis Dates	SUB-SLAB SAMPLES						AMBIENT AIR SAMPLES		INDOOR AIR SAMPLES			
	Cupolex Ports					Geo-Vent Stack						
	North Port		South Port		Sub-slab		Outdoor	Park	Southwest Side		outheast Sid	General
	Sample	Duplicate	Sample	Duplicate	Sample	Sample	Sample	Sample	Sample	Duplicate	Sample	Sample
TRICHLOROETHYLENE (µg/m3)												
HBIAQC	1.79											
SSRA	11.28											
July 24-25, 2014, CRA	1.01	1.09	0.36			NA	0.11					
August 8-9, 2014, CRA	1.58	1.54	1.86			NA	<0.104					
August 22, 2014, exp.						NA	<0.269		<0.269	<0.269	<0.269	
October 16, 2014 exp.					3.52	NA	<0.269					<0.269
November 19, 2014 exp.					6.51	249	<0.269	<0.269				<0.269
December 22-23, 2014, C	4.9		5.4	5.2		179	<0.11					<0.11
January 20-21, 2015, CR	1.8		2.11	2.25		79	<0.11					<0.11
February 24-25, 2015, CF	0.94		1.03	0.97		120	<0.11					<0.11
March 17-18, 2015, CRA	1.06		1.11	1.18		115	<0.11					<0.11
April 16-17, 2015, CRA	1.97		2.09	2.13		71.5	<0.11					<0.11
May 25-26, 2015, CRA	5.00		4.43			NA	<0.11					<0.11
June 16-17, 2015, CRA	10.4		11.8			NA	<0.11					<0.11
July 16-17, 2015, CRA	10.6		11.1			114.0	<0.11					<0.11
August 19-20, 2015, CRA	15.7		19.7			163	0.11					<0.11
September 22-23, 2015, (	11.4		12.7			63.3	0.15					0.160
October 15-16, 2015, CR	7.2		7.0			71.3	0.19					<0.11
November 16-17, 2015, C	4.28		3.51			58.5	<0.11					<0.11
December 16-17, 2015, C	6.3		5.4			169	<0.11					<0.11
January 20-21, 2016, CR	0.99		1.35			44.9	<0.11					<0.11
February 17-18, 2016, CF	1.02		0.91			57.5	<0.11					<0.11
March 16-17, 2016, CRA	1.75		1.45			66.6	<0.11					<0.11
April 13-14, 2016, CRA	1.21		1.26			36.2	<0.11					<0.11
May 18-19, 2015, CRA	1.91		1.43			48.3	<0.11					<0.11
June 15-16, 2016, CRA	4.03		3.12			56.4	<0.11					<0.11
July 20-21, 2016, CRA	7.3		6.30			67.7	0.22					<0.11/0/.15
August 18-19, 2016, CRA	15.1		15.00			95.7	<0.11					<0.11
September 14-15, 2016, (	11		11.40			85.3	<0.11					<0.11
October 18-19, 2016, CR	11		11.10			91.0	0.16					<0.11
November 16-17, 2016, C	2.07		1.60			20.6	<0.11					<0.11

HBIAQC — Health Based Indoor Air Quality Criteria (µg/m3)
SSRA — Site Specific Risk Assessment (ug/m3)
NA — Not Available
(light yellow) Results exceeding HBIAQC
(orange) Results exceeding both HBIAQC & SSRA

CASE STUDY: Guelph Commercial Site:
Air Monitoring Program



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CASE STUDY: Guelph Commercial Site:
Vapour Mitigation System

Based on those findings, the Tenant raised the prospect of a breach in the membrane system!

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CASE STUDY: Guelph Commercial Site:
Vapour Mitigation System

So what was really happening?

The installer asked us to use the data to see if something else was at play.

Could this be explained by, say, Diffusion?

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CASE STUDY: Guelph Commercial Site:

Diffusion Calculations

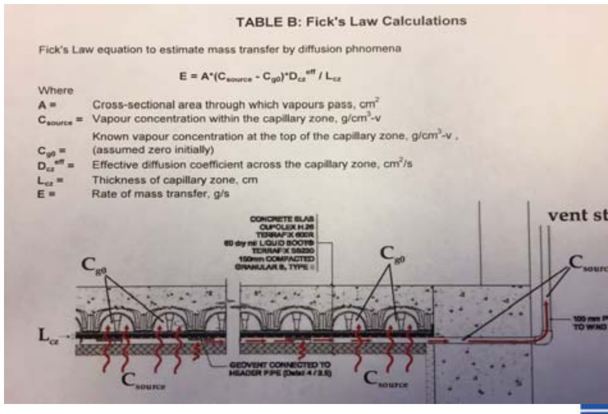

TABLE B: Fick's Law Calculations

Fick's Law equation to estimate mass transfer by diffusion phnomena

$$E = A^*(C_{source} - C_{g0})^*D_{cz}^{eff} / L_{cz}$$

Where

$A =$ Cross-sectional area through which vapours pass, cm^2

$C_{source} =$ Vapour concentration within the capillary zone, g/cm^3-v

$C_{g0} =$ Known vapour concentration at the top of the capillary zone, g/cm^3-v , (assumed zero initially)

$D_{cz}^{eff} =$ Effective diffusion coefficient across the capillary zone, cm^2/s

$L_{cz} =$ Thickness of capillary zone, cm

$E =$ Rate of mass transfer, g/s

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CASE STUDY: Guelph Commercial Site:

LIQUID BOOT ®

SPRAY-APPLIED GAS VAPOR BARRIER

TESTING DATA

CHEMICAL & PHYSICAL PROPERTIES		
CHEMICAL PROPERTY	TEST METHOD	RESULT
Acid Exposure (10% H_2SO_4 for 90 days)	ASTM D543	Less than 1% weight change
Benzene Diffusion Test	Tested at 43,000 ppm	2.90 x 10^{-11} m^2/day
Chemical Resistance: VOCs, BTEXs (tested at 20,000 ppm)	ASTM D543	Less than 1% weight change
Chromate Exposure (10% Chromium6+ salt for 31 days)	ASTM E96	Less than 1% weight change
Diesel (1000 mg/l), Ethylbenzene (1000 mg/l), Naphthalene (5000 mg/l) and Acetone (500 mg/l) Exposure for 7 days	ASTM D543	Less than 1% weight change; Less than 1% tensile strength change
Hydrogen Sulfide Gas Permeability	ASTM D1434	None Detected
Methane Permeability	ASTM 1434-82	Passed*
Microorganism Resistance	ASTM D4068-88	Passed*
Oil Resistance	ASTM D543-87	Passed*
PCE Diffusion Coefficient	Tested at 120 mg/L	1.32 x 10^{-13} m^2/sec
Radon Permeability	Tested by US Dept. of Energy	Zero permeability to Radon (222Rn)
TCE Diffusion Coefficient	Tested at 524 mg/L	9.07 x 10^{-13} m^2/sec

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CASE STUDY: Guelph Commercial Site:
Diffusion Calculations

Estimated Accumulation of Tricholorethylene in CUPOLEX Layer due to diffusion alone through Liquid Boot

		Units	Calculations
A =	Area of Liquid Boot membrane (Area of Building B)	m^2	837.5
C_{source} =	Concentration of contaminant below Liquid Boot (Conc. in Geovent stack)	$\mu g/m^3$	249
C_{g0} =	Concentration of contaminant in Cupolex, Assumed to be zero	$\mu g/m^3$	0
D_{cz}^{eff} =	Effective diffusion coefficient of contaminant	m^2/s	9.07E-13
L_{cz} =	Thickness of Liquid Boot membrane	m	2.00E-03
E =	Rate of mass transfer	µg/s	9.45718E-05
	Estimated transfer of contaminant in Cupolex during one month	µg/month	245.1299922
V =	Volume of Cupolex layer (837.5*0.2)	m^3	167.5
	Estimated accumulation of contaminant in Cupolex during one month	$\mu g/m^3$/month	1.46E+00

Calculation based on 1 month
1 month = 2592000 seconds

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CASE STUDY: Guelph Commercial Site:
Summary of Findings

So, in summary, the diffusion calculations predicted that at this site, upto 1.5 $\mu g/m^3$ per month could be expected to accumulate in the CUPOLEX® layer by diffusion alone.

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CASE STUDY: Guelph Commercial Site: Discussion

Do the findings make sense?

-Note that the maximum concentration of TCE in groundwater was 2.2 µg/L

-Readings in the Geovent (bypass) ranged from about 100 to 250 µg/m^3

-Findings predicted <u>upto 1.5 µg/m^3 per month got past the membrane</u>.

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CASE STUDY: Guelph Commercial Site: Discussion

REMEMBER:

- Soil contamination is measured in µg/g or ppm
- Groundwater contamination is measured in µg/L or ppb
- Air contamination is measured in µg/m3 or ppt

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CASE STUDY: Guelph Commercial Site: Discussion

- Therefore, groundwater TCE level of 2.2 μg/L can be expressed as 2200 ppt – which was the volatile source.
- Of this, the amount bypassing the building through the venting system ranged from 100 to 250 ppt, roughly 10-25 % of the source, which is reasonable.
- Of this, a small fraction of upto 1.5 ppt/month was predicted to diffuse through the membrane (and accumulate in the CUPOLEX® layer).

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CASE STUDY: Guelph Commercial Site: Discussion

- Based on these findings, it was shown that appreciable amounts of volatile contaminants can enter buildings via the diffusion pathway, so no breach was inferred.
- This phenomenon is not usually obvious at low concentrations due to dilution and indoor air changes.
- However, if VOC source levels are of the order of thousands of ppbs, such as at DNAPL or LNAPL sites, diffusion matters!

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CASE STUDY: Guelph Commercial Site: Discussion

What are the lessons from this Study?

1. Mitigation systems are seldom impermeable. The diffusion pathway should not be ignored.
2. Selection of your membrane is critical, depending on what the source concentration of the VOCs is.
3. Installation details and workmanship are important.
4. Always rough-in to provide for active venting.

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What Services Does AiMS Offer?

- Expertise includes the following:
  - Phase I/II ESAs for Commercial Mortgage Financing
  - Phase III Site Cleanup/Remediation Management
  - Underground Tank Removal Supervision/Testing
  - Design of Vapour Intrusion Systems
  - Indoor Air Quality Monitoring

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THANK YOU!

Questions?