

Identifying Safer Solvents Using Hansen Solubility Parameters

Professor Steven Abbott

Steven Abbott TCNF Ltd

A Training Webinar for TURI

Note: The webinar is an outline as the main content is based on live use of the HSPiP software and apps

Applying solubility thinking to TUR

- We will see that a simple but powerful solubility approach allows us to optimise our replacement strategy for
 - Solvents
 - Polymers
 - Plasticisers
 - Fillers
 - etc.
- As a bonus, the same approach can be used for your general formulation development

Who am I?

- A UK-based chemist – who did his Oxford PhD at Harvard
- An industrialist concerned with real-world issues
- A Visiting Professor who likes to bring the best possible science to industrial processes
- Someone who programs powerful technical software and apps
 - Co-author of HSPiP being used today
- An independent consultant

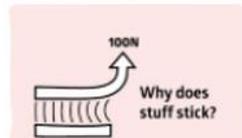
www.stevenabbott.co.uk

- Lots of AbbottApps resources, including Practical Solubility. All free and run on all platforms – PC, Mac, tablets, phones

Trainer, consultant, author ...
Good science, clearly explained
Free app-based resources ready for use
Click below to explore the resources

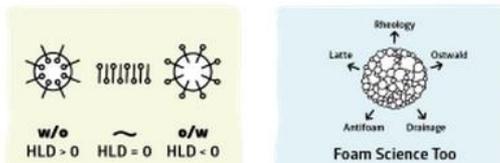
Professor Steven Abbott
Science for the real world

Practical Adhesion



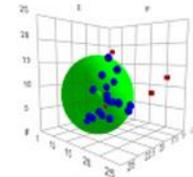
Adhesion science apps

Practical Surfactants & Foams



Learn surfactant & foam science via apps

Practical Solubility



Learn solubility science via apps

Practical Nanocoatings (Coming soon)



Learn nanocoating science via apps

AbbottApps

AbbottApps
Science Delivered to your Screen

Easy to use, powerful, run on all devices

Training and Consulting



Yes, I train, consult, write books ...

My thanks

- To the very capable TURI team for setting up this webinar

Solubility?

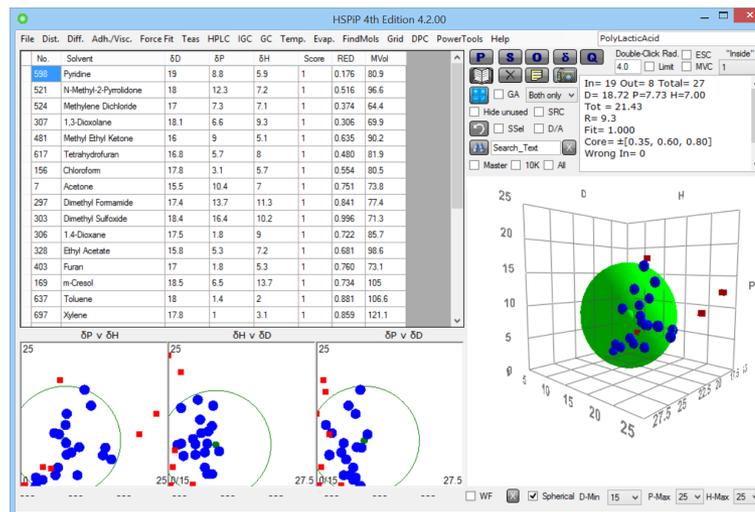
- Even if they are green and safe:
 - A solvent can't clean or dissolve without the right solubility behaviour
 - A plasticiser is useless (it will bloom over time) if it is insoluble in the polymer
 - A protective polymer is useless if the chemical can readily dissolve and diffuse through it
 - A particle or filler won't deliver its promise if it is not compatible with (soluble in) the system

But we know about solubility

- No we don't!
 - Hydrophobic/Hydrophilic, Polar/Non-polar, LogP are too simplistic
 - UNIFAC is usually too expensive and too specialised
 - COSMO-RS (based on quantum calculations) is wonderful but not usually for our sorts of issues
- With 3 Hansen Solubility Parameters we can do a lot
 - Many HSP are in the public domain and my Practical Solubility site has some useful apps and datasets
 - For serious use, HSPiP (Hansen Solubility Parameters in Practice) is the platform of choice – and is used by TURI

3 Hansen Solubility Parameters

- δD – Dispersion
 - The polarisability of a molecule
 - Alkanes are too boring to be polarisable $\delta D \sim 14$
 - Aromatics are more polarisable $\delta D \sim 18$
 - Chloro-aromatics even more polarisable .. $\delta D \sim 19$
 - ... etc



3 HSP

- δP – Polar
 - Alkanes, aromatics are not polar $\delta P \sim 0$
 - Acetonitrile is massively polar $\delta P \sim 18$
 - The average chemist would have no problem in agreeing with the relative δP rankings of most simple molecules

3 HSP

- δH – Hydrogen bonding
 - Alkanes, aromatics $\delta H \sim 0$
 - Methanol > Ethanol $\delta H \sim 20$
 - Acetone $\delta H \sim 5$
 - It has the ability to be an acceptor in H-bonds
 - Again, the average chemist would have no problem in agreeing with the relative δH rankings of most simple molecules

(+1)

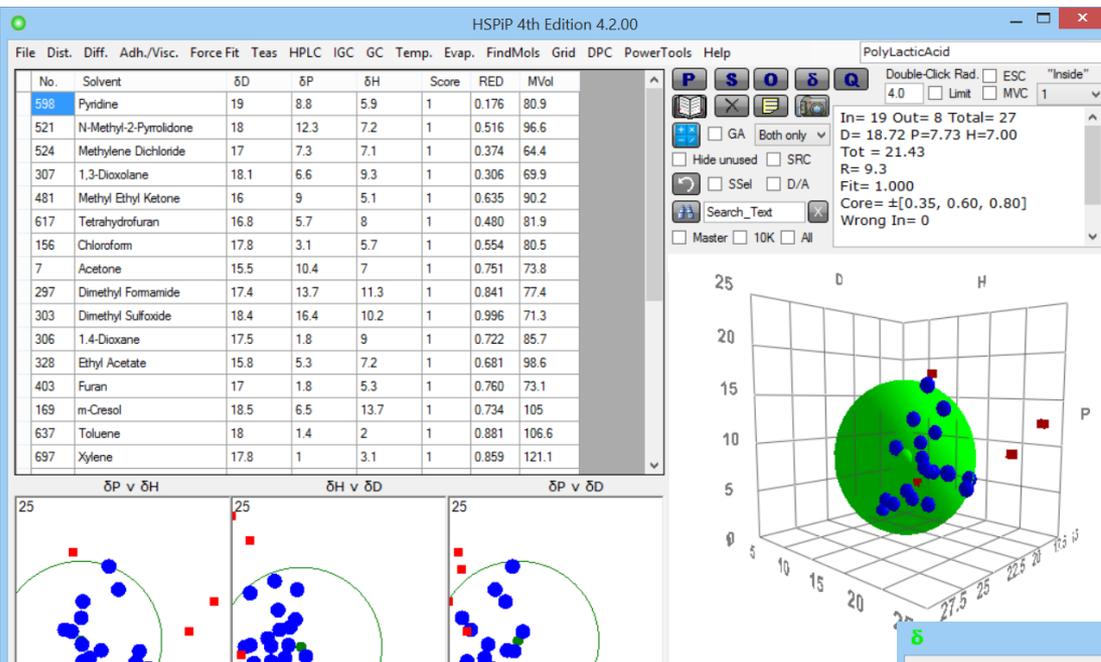
- MVol
 - Molar Volume constrains the numbers
 - HSP come from Cohesive Energy *Density*
 - So bigger means more Cohesive Energy ...
 - ... but not necessarily more Cohesive Energy Density
- For solubility “Small is Beautiful”
 - thermodynamics (entropy)
 - kinetics (fast diffusion)
- But we’ll stick with 3 for the rest of the webinar

Solubility and Compatibility

- “Like dissolves like”, “Like is compatible with like”
- Calculate “like” with a simple Distance formula:
 - $D^2 = 4(\delta D_1 - \delta D_2)^2 + (\delta P_1 - \delta P_2)^2 + (\delta H_1 - \delta H_2)^2$
- Just the standard distance in 3D space, with a tweak for δD
- If things are very alike then D is small, if they are not alike, D is large
 - Activity coefficients and/or χ parameters calculated from e^{-D^2}
- The famous HSP formula, working for 40+ years
 - Distance is sometimes shown as Ra

HSP values

- Thermodynamic relationships:
 - Originally derived for solvents from enthalpy of vapourisation, Refractive index, Dipole moment
- OK for solvents but not for solids and polymers
 - So measure them via a “20 solvent test”
 - Let’s measure the HSP of Poly lactic acid
 - Estimate automatically from SMILES or MolFile
 - Let’s estimate the HSP of ibuprofen
- HSPiP contains tables of solvents, polymers, GRAS, flavours & fragrances, EAFUS...



The HSP Sphere for PLA in 27 solvents

Get the SMILES of ibuprofen from e.g. ChemSpider and calculate automatically

ChemSpider
Search and share chemistry

About More Searches Web APIs Help

Ibuprofen

ChemSpider ID: 3544

Molecular Formula: C₁₃H₁₈O₂

Average mass: 206.281 Da

Monoisotopic mass: 206.130676 Da

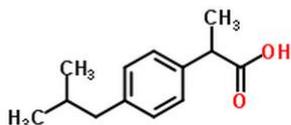
▼ Systematic name

2-(4-Isobutylphenyl)propanoic acid

▼ SMILES and InChIs

SMILES:

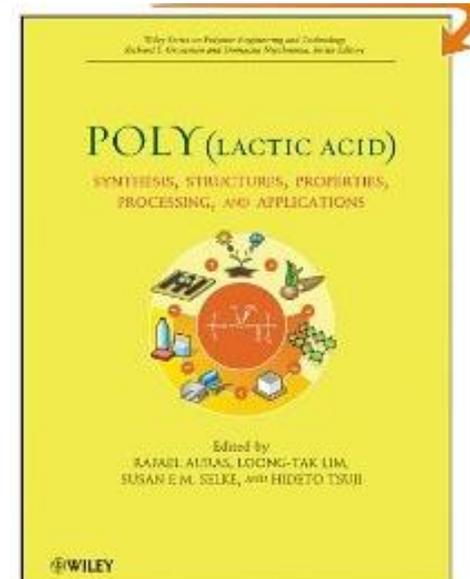
CC(C)Cc1ccc(cc1)C(C)C(=O)O



? 2D 3D Save Zoom

Predicting PLA

- Poly Lactic Acid
 - an important “green” polymer
 - lots of wasted work trying to find plasticisers, fillers, nanoclay barrier properties, controlled release
 - the basics sorted out purely with HSP
 - read my predictions for yourself
 - e.g. don't package cinnamon buns in PLA



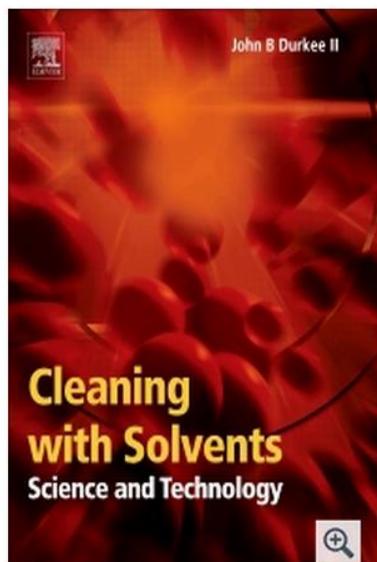
Replacing solvents

- If you know the HSP of your solvent then the best solvent will have a similar HSP
 - Except that “best” also includes cost, odour, vapour pressure, VOC ...
- Highly unlikely that any *single* solvent will give you what you need
 - You would probably know it already as it’s easy enough to test a bunch of single solvents

The best single solvent for cleaning?

- The John Durkee book is based solidly on HSP principles
 - The tradeoffs between greenness, low VOC and ability to clean (small HSP Distance) discussed in depth

Cleaning with Solvents: Science and Technology, 1st Edition

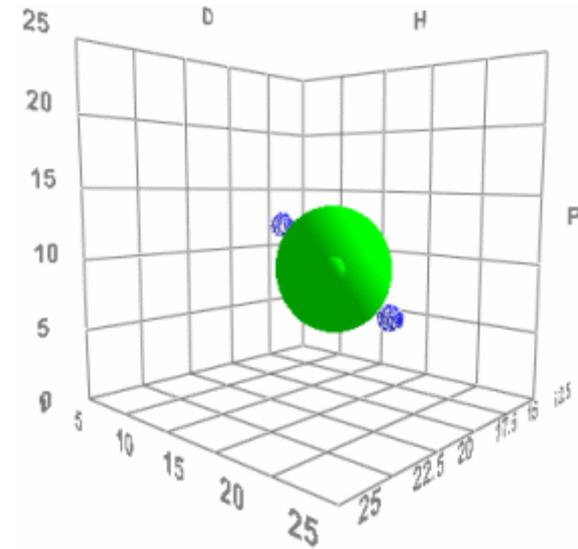


Author : J Durkee
Release Date: 30 Jan 2014
Imprint: William Andrew
eBook ISBN : 9781455731619
Print Book ISBN : 9781455731312
Pages: 780

In this practical handbook, John Durkee guides readers through the technologies and materials of the solvent-based cleaning of surfaces, explaining how to implement successful cleaning procedures and exploring regulatory frameworks, economic factors and environmental concerns.

Smart solvent blends

- Take two *non*-solvents for a polymer
- Mix them 50:50
- What do you get?
- If you do it according to the numbers you can get a good solvent
- The birth of “rational solvent blends”
 - optimise for solubility along with cost, compliance, controlled solubility during evaporation
- Of course you don’t have to use *bad* solvents, this example is to make a point



A green example

- FAME (Fatty Acid Methyl Esters) are too boring to be much use, but are “green” [16.4, 2.6, 4.5]
- Glycerol carbonate comes from bio-glycerol, CO₂ (in principle) and is bio-degradable – but is much too polar to be highly useful [17.9, 25.5, 17.4]
- A 60:40 mix is an impressive match for a great (but unusable) solvent like Dimethyl Acetamide

A green example

Solvent	δD	δP	δH	MVol	Other Names	RER	Weight	Vol%		Distance	AA	
FAME	16.4	2.6	4.5	280.9	Fatty Acid Methyl Ester	0.2	100	60.0	<input checked="" type="checkbox"/>	10.60	9.6	2
Glycerol Carbonate	17.9	25.5	17.4	83.2		0	100	40.0	<input checked="" type="checkbox"/>	15.90	-8.244	-2
Methyl iso-Butyl Carbinol	15.4	3.3	12.3	127.2	MIBCOL	27	100		<input type="checkbox"/>	8.92	7.56	1
Methyl Iso-Butyl Ketone...	15.3	6.1	4.1	125.8	4-Methyl-pentan-2-one	162	100		<input type="checkbox"/>	8.68	6.686	1
Methyl iso-Amyl Ketone	16	5.7	4.1	141.3	MIAK	50	100		<input type="checkbox"/>	8.57	7.259	1
Methyl Cyclohexane	16	0	1	128.2		300	100		<input type="checkbox"/>	14.81	7.001	1
Methyl Ethyl Ketone (M...	16	9	5.1	90.2	2-Butanone	380	100		<input type="checkbox"/>	5.90	7.063	1
Methyl Oleate	16.2	3.8	4.5	340.7		0	100		<input type="checkbox"/>	9.66	7.516	2
Methylene Chloride	17	7.3	7.1	64.4	Dichloromethane	1450	100		<input type="checkbox"/>	5.24	7.08	1
N,N-Dimethyl Acetamide	16.8	11.5	10.2	93	DMA	13.8	100		<input type="checkbox"/>	0.00	7.3	1
N,N-Dimethyl Formamid...	17.4	13.7	11.3	77.4	DMF	10	100		<input type="checkbox"/>	2.74	7.241	1
Methyl Cellosolve	16	8.2	15	79.3	2-Methoxy Ethanol	53	100		<input type="checkbox"/>	6.04	8.097	1
Methyl Propyl Ketone	16	7.6	4.7	107.3		240	100		<input type="checkbox"/>	6.93	7.354	1
N-Methyl-2-Pyrrolidone (NMP)	18	13.3	7.3	99.1	NMP	3	100		<input type="checkbox"/>	3.02	7.000	2

Target

δD	δP	δH
16.8	11.5	10.2
-2.0	-2.0	2.0

Calculated

17.0	11.8	9.7
------	------	-----

Delta

0.2	0.3	-0.5
-----	-----	------

Distance RED Wt. Err

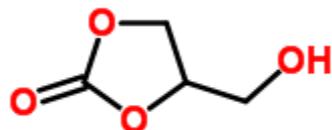
0.7	0.09	0.0
-----	------	-----

DMA is the target of 16.8, 11.5, 10.2

The 60:40 blend is 17, 11.8, 9.5

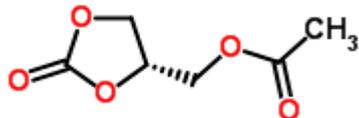
The Distance is 0.7 – rather close

Rational green solvent design



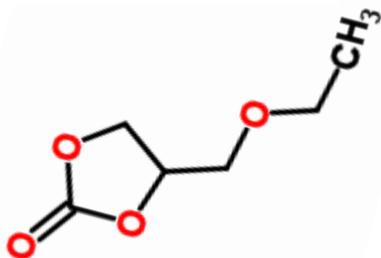
Glycerol carbonate
 δP , δH too high
Only good in mixtures

[17.9, 25.5, 17.4]



Glycerol carbonate acetate
Excellent potential solvent

[17.1, 14.7, 9.2]

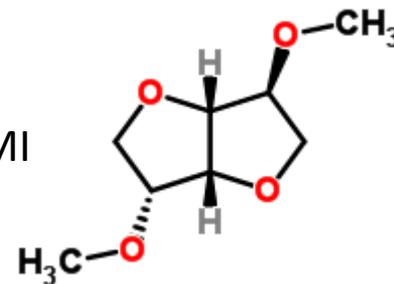


Glycerol carbonate ethyl ether
Excellent potential solvent

[16.8, 18.5, 8.7]

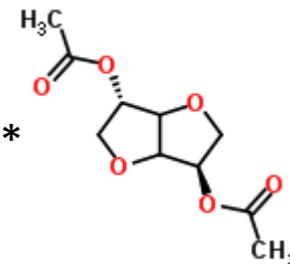
Assumes the carbonates can be made without phosgene!

Dimethyl Isosorbide – DMI
Excellent solvent for skin
delivery
But *not* green (2 reasons)



[17.6, 7.1, 7.5]

Diacetate of Isosorbide
Should be excellent solvent*
Will be green



[16.7, 7.5, 8.9]

*Solid at RT – needs ester mixture

Cleaning a nylon residue

A personal example

- Toluene/IPA an excellent* solvent blend for a specific nylon used on a coating machine
- Operators hated the cleaning job
- I had tested it on the small scale and proved it was fine – but on the large scale it was awful!
- Reformulated using HSPiP: DBE:Dowanol PnB
 - Larger distance, somewhat slower
 - Much less volatile – just leave then wipe off later
 - DBE:Dowanol PM not so good because PM too volatile
 - Great success!

*This was some time ago before toluene tox limits were lowered even further

The original
blend.
RER ~160

Solvent Optimizer

Solvent	δD	δP	δH	MVol	Other Names	RER	Weight	Vol%	Distance	AA
2-Propanol	15.8	6.1	16.4	76.9		150	100	50	7.87	8.878
Toluene	18	1.4	2	106.6		190	100	50	7.90	6.951
Methyl iso-Butyl Carbinol	15.4	3.3	12.3	127.2	MIBCOL	27	100		4.34	7.56
Methyl iso-Amyl Ketone	16	5.7	4.1	141.3	MIAK	50	100		5.73	7.259
Methyl Cellosolve	16	8.2	15	79.3	2-Methoxy Ethanol	53	100		7.50	8.097
Methyl Cyclohexane	16	0	1	128.2		300	100		9.22	7.001
Methyl Ethyl Ketone (M...)	16	9	5.1	90.2	2-Butanone	380	100		6.86	7.063
Methyl Iso-Butyl Ketone...	15.3	6.1	4.1	125.8	4-Methyl-pentan-2-one	162	100		6.45	6.686

The revised
blend.
RER ~ 5

Solvent Optimizer

Solvent	δD	δP	δH	MVol	Other Names	RER	Weight	Vol%	Distance	AA
Dibasic Esters (DBE)	16.2	6.5	8.4	159	Di-Basic Ester; Dimethyl...	1	100	55.0	3.14	7.237
Propylene Glycol Mono...	15.3	4.5	9.2	132	PnB; 1-Butoxypropan-2-ol	7	100	45.0	3.28	7.241
Aromatic hydrocarbons	18	1	3	100		1	100		7.15	6.976
Diethylene Glycol Mono...	16	7	10.6	170.4	DB; 2-(2-butoxyethoxy)et...	3	100		3.93	8.456
n-Amyl Alcohol	15.9	5.9	13.9	108.6	n-Pentanol	14.8	100		5.52	7.458
n-Amyl Acetate	15.8	3.3	6.1	148		67	100		3.83	7.334
Acetonitrile	15.3	18	6.1	52.9		230	100		14.88	7.074
n-Butyl Acetate	15.8	3.7	6.3	132.6		100	100		3.64	7.028
Benzyl Alcohol	18.4	6.3	13.7	103.8		0.6	100		5.96	7.582
Aliphatic hydrocarbons	14	0	0	100		1	100		11.52	6.886
t-Butyl Alcohol	15.2	5.1	14.7	96		160	100		6.60	7.133
1-Butanol	16	5.7	15.8	92		43	100		7.10	7.838
t-Butyl Acetate	15	3.7	6	134.8		280	100		4.97	7.071
Butyl Benzoate	18.3	5.6	5.5	178.1		0.3	100		4.98	7.596
Butyl Diglycol Acetate	16	4.1	8.2	208.2	BDGA; 2-(2-butoxyethox...	0.1	100		2.08	7.831
Butyl Glycol Acetate	15.3	7.5	6.8	171.2		4	100		5.45	7.256
Cyclohexanone	17.8	8.4	5.1	104.2		29	100		6.42	7.313
γ -Butyrolactone (GBL)	18	16.6	7.4	76.5	Dihydro-furan-2-one	3	100		13.11	7.256
Caprolactone (Epsilon)	19.7	15	7.4	110.8	Oxepan-2-one	0.1	100		12.65	7.831
Cyclohexane	16.8	0	0.2	108.9		560	100		9.77	7.009
Cyclohexanol	17.4	4.1	13.5	105.7		1	100		4.42	7.15
Benzyl Benzoate	20	5.1	5.2	190.3		0.1	100		7.49	7.499
Cyclopentyl Methyl Ether	16.7	4.3	4.3	116.5	CPME	190	100		4.94	6.917
Di-iso-Butyl Ketone	16	3.7	4.1	177.4		15	100		5.41	7.349
Diacetone Alcohol	15.8	8.2	10.8	124.3	4-Hydroxy-4-Methyl-2-Pe...	12	100		5.17	7.874
n-Butyl Propionate	15.7	5.5	5.9	149.3		45	100		4.42	7.4

Smart evaporation in solvent blends

- Solvent blends allow smart tricks
- HSPiP has the RER of the solvents (or Antoine Constants for VP at higher T)
- So we can have the best solvent evaporate faster
 - To make the solute crash out quickly
- Or we can have the worse solvent evaporate faster
 - To keep things in solution for as long as possible

A blend of CPME and ethyl lactate is a good match for the target
 CPME is a worse solvent but is more volatile (RER=190 versus 22)
 So the Ra (HSP Distance) stays OK through the whole process

Solvent Optimizer

Solvent	δD	δP	δH	MVol	Other Names	RER	Weight	Vol%	Distance	AA
Cyclopentyl Methyl Ether	16.7	4.3	4.3	116.5	CPME	190	100	50	6.23	6.917
Ethyl Lactate	16	7.6	12.5	115		22	100	50	2.74	9.091
1,3-Dioxolane	18.1	6.6	9.3	69.9		500	100		4.06	7.117
Diethylene Glycol Mono...	16	7	10.6	170.4	DB; 2-(2-butoxyethoxy)et...	3	100		0.81	8.456
Aliphatic hydrocarbons	14	0	0	100		1	100		12.64	6.886
n-Amyl Alcohol	15.9	5.9	13.9	108.6	n-Pentanol	14.8	100		3.97	7.458
Acetonitrile	15.3	18	6.1	52.9		230	100		12.25	7.074
Benzyl Alcohol	18.4	6.3	13.7	103.8		0.6	100		5.91	7.582
Benzyl Benzoate	20	5.1	5.2	190.3		0.1	100		9.26	7.499
n-Amyl Acetate	15.8	3.3	6.1	148		67	100		5.08	7.334
Aromatic hydrocarbons	18	1	3	100		1	100		9.68	6.976
n-Butyl Acetate	15.8	3.7	6.3	132.6		100	100		4.68	7.028
t-Butyl Acetate	15	3.7	6	134.8		280	100		5.36	7.071

Step	Total	δD	δP	δH	Ra	S1	S2
0	100	16.4	6.0	8.4	1.8	50.0	50.0
1	91.2	16.3	6.1	8.7	1.4	46.2	53.8
2	82.9	16.3	6.2	9.1	1.1	42.0	58.0
3	75.2	16.3	6.4	9.4	0.7	37.5	62.5
4	68.2	16.2	6.5	9.8	0.3	32.7	67.3
5	61.8	16.2	6.7	10.2	0.3	27.7	72.3
6	56.1	16.2	6.9	10.6	0.7	22.7	77.3
7	51.1	16.1	7.0	11.0	1.2	17.9	82.1
8	46.7	16.1	7.2	11.4	1.5	13.5	86.5
9	43.0	16.1	7.3	11.7	1.9	9.7	90.3
10	39.8	16.0	7.4	12.0	2.1	6.6	93.4
11	37.1	16.0	7.5	12.1	2.4	4.3	95.7
12	34.7	16.0	7.5	12.2	2.5	2.6	97.4

Solubility Graph Ctrl-Click to disable a solvent Only use bad solvents beyond R Search_Text C:\Users\Steven\Doc...\TURI Evap.sof

Looking for inspiration

Look for molecules in a given range of HSP and, optionally, BPT

Find Molecules

Include δD in search
 Include δP in search
 Include δH in search
 Include BPT in HSP and Func. search

16 <= δD <= 17.5
 3.0 <= δP <= 6.0
 5.0 <= δH <= 9.0
 50.0 <= Bpt °C <= 100.0

Include Do/Ac in search
 0.0 <= δH_{do} <= 5.0
 0.0 <= δH_{ac} <= 5.0

Normal Cyclic Aromatic Other
 Normal Cyclic Aromatic Other
 Normal Cyclic Aromatic Other

No.	Name	CAS	δD	δP	δH	$\delta HD/A$	BPT °C
105	n-Butyl Amine	109-73-9	16.2	4.5	8	5.1/6	77
214	1,1-Dibromoethylene	593-92-0	16.2	4.8	7	0.1/4	99.5
277	Dihydropyran	110-87-2	17.5	5.5	5.7	0.3/5.8	86
315	Divinylsulfide	627-51-0	16.5	4.6	5.6	0.1/2.7	84
434	Isobutyleneoxide	558-30-5	16.1	4.8	5.8	0.1/4.9	52
511	Methyl Vinyl Sulfide	1822-74-8	16.4	4.9	6	0.1/3.6	58.0
519	2-Methyl-1,3-Dioxolane	497-26-7	17.3	4.8	5.8	0.5/7.4	83
547	Oxalylchloride	79-37-8	16.1	3.8	7.5	1.3/6.9	64
568	1-Propanethiol	107-03-9	16.1	5.8	5.7	0.1/5.2	68
617	Tetrahydrofuran (THF)	109-99-9	16.8	5.7	8	0.5/5.7	66
625	2-Thiabutane	624-89-5	16.2	5.9	5.3	0.3/4.1	64.9

HSD Output
 10,000 set
 Limit to 200
 12 match(es) found
 The data have been placed on the Clipboard

Output in Excel format too

No.	Name	CAS	SMILES	Formula	δD	δP	δH	δH_{Don}	δH_{Acc}	MWt	Density	MVol	Area	Ovality	BPT	MPt
105	n-Butyl Amine	109-73-9	CCCCN	C4H11N	16.2	4.5	8	5.1	6	73.14	0.741	98.8	131.19	1.267	77	-49
214	1,1-Dibromoethylene	593-92-0	C=C(Br)Br	C2H2Br2	16.2	4.8	7	0.1	4	185.85	2.192	85.3	106.92	1.146	99.5	-49.3
277	Dihydropyran	110-87-2	C1CCOC=C	C5H8O	17.5	5.5	5.7	0.3	5.8	84.12	0.907	91.2	118.67	1.212	86	-102.1
315	Divinylsulfide	627-51-0	C=CSC=C	C4H6S	16.5	4.6	5.6	0.1	2.7	86.16	0.894	93.6	120.09	1.182	84	-89.5
434	Isobutyleneoxide	558-30-5	CC1(CO1)C	C4H8O	16.1	4.8	5.8	0.1	4.9	72.11	0.811	90	114.69	1.229	52	-111.5
511	Methyl Vinyl Sulfide	1822-74-8	CSC=C	C3H6S	16.4	4.9	6	0.1	3.6	74.15	0.876	82.1	106.62	1.144	58	-127.7
519	2-Methyl-1,3-Dioxolane	497-26-7	CC1OCCO:C	C4H8O2	17.3	4.8	5.8	0.5	7.4	88.11	0.974	89.8	128.04	1.314	83	-66.2
547	Oxalylchloride	79-37-8	C(=O)C(=C	C2Cl2O2	16.1	3.8	7.5	1.3	6.9	126.93	1.559	85.8	106.76	1.175	64	-10
568	1-Propanethiol	107-03-9	CCCC	C3H8S	16.1	5.8	5.7	0.1	5.2	76.16	0.842	90.5	114.52	1.172	68	-113
617	Tetrahydrofuran (THF)	109-99-9	C1CCOC1	C4H8O	16.8	5.7	8	0.5	5.7	72.11	0.886	81.9	106.26	1.191	66	-109
625	2-Thiabutane	624-89-5	CSCC	C3H8S	16.2	5.9	5.3	0.3	4.1	76.16	0.846	91	115.01	1.184	64.9	-124
686	Vinyl Ethyl	627-50-9	CCSC=C	C4H8S	16.4	5.8	6.3	0.1	3.2	88.17	0.867	101.3	128.48	1.219	91	-120.8

Read across

Compare two molecules using their SMILES. Can then “read across” in safety terms with whatever parameters are relevant to you

Using EtOH and 2-PrOH as an example where you know what to look for!

The screenshot shows a software window titled "DIY" with a menu bar including "Y-MB", "Stefanis-Panayiotou", "Van Krevelen", "Hoy", "Numbers", "Polymers", "HSE", "Azeotropes/VP", "Solubility", "Miscibility", and "Surfactants". The main area is divided into two columns for "SMILES or InChI input Chemical 1" and "SMILES or InChI input Chemical 2".

Chemical 1: SMILES CCO, Formula C2H6O, HSP Distance 4.8. Parameters: δD 15.62, δP 9.3, δH 17.19, δTot 25.0, MVol 58.2, MWt 46.1. Database match(es): Et:1 OH:1, 325 Ethanol 15.8 8.8, 19.4 12.5/11.3.

Chemical 2: SMILES CC(C)O, Formula C3H8O. Parameters: δD 15.47, δP 7.18, δH 12.84, δTot 21.3, MVol 75.7, MWt 60.1. Database match(es): iso_Pr:1 2_OH:1, 570 2-Propanol 15.8 6.1, 16.4 10/10.

Additional parameters for both: VP @25°C, RER, Flash point, Log(OHR), VP @ °C, log(Ksoil), log(Kow), log(S), MP °C, BP °C, RI, Density, HAC. A temperature input field is set to 25.0 °C.

Parameter	Chemical 1 (EtOH)	Chemical 2 (2-PrOH)
Formula	C ₂ H ₆ O	C ₃ H ₈ O
HSP Distance	4.8	
δD	15.62	15.47
δP	9.3	7.18
δH	17.19	12.84
δTot	25.0	21.3
MVol	58.2	75.7
MWt	46.1	60.1
VP @25°C	52.33	81.47
RER	109	67.0
Flash point	21	3
Log(OHR)	-11.54	-11.36
VP @ °C	52.33	81.47
log(Ksoil)	0.41	0.59
log(Kow)	-0.19	0.25
log(S)	2.07	1.73
MP °C	-94.3	-94.1
BP °C	83.2	74.3
RI	1.371	1.368
Density	0.791	0.793
HAC	3	4

EAFUS, GRAS, TURI

- HSPiP has lots of data tables, e.g. EAFUS
 - Everything Added to Food in the United States

No.	Solvent	δD	δP	δH	Score	RED	MVol	CAS
694	Acetal	15	3.4	4	-	-	143.9	105-57-7
695	Acetaldehyde	14.7	12.5	7.9	-	-	56.5	75-07-0
696	Acetaldehyde Di-Cis-3-He...	16.1	3.4	4.5	-	-	260.8	63449-64-9
698	Acetaldehyde Di-Isobutyla...	15.0	3.4	5.1	-	-	210.8	5669-09-0
697	Acetaldehyde Diisoamyl A...	15.2	3.2	5.0	-	-	243.1	13002-09-0
699	Acetaldehyde Ethyl Cis-3-...	15.8	3.9	4.4	-	-	200.9	28069-74-1
700	Acetaldehyde Ethyl Isobut...	15.1	3.9	4.8	-	-	175.9	6986-51-2
10	(+/-)-Acetaldehyde Ethyl I...	15.2	4.2	4.8	-	-	158.1	25334-93-4
701	Acetaldehyde Phenethyl ...	17.3	4.1	4.9	-	-	219.5	7493-57-4
702	Acetaldehyde, Butyl Phen...	17.2	4.5	4.7	-	-	236.5	64577-91-9
703	Acetamide	17.3	18.7	19.3	-	-	59	60-35-5
704	Acetanisole	18.9	11.2	7	-	-	137.8	100-06-1
705	Acetic Acid	14.5	8	13.5	-	-	57.6	64-19-7
706	Acetic Anhydride	16	11.7	10.2	-	-	95	108-24-7
707	Acetoin	16.2	12.1	18.2	-	-	88.3	513-86-0
708	Acetic Anhydride, Methyl...	17.1	6.8	14.8	-	-	128.5	64000-22-2

- e.g. GRAS but is only ~80 chemicals
- We can have TURI lists
 - Started with 800+ of the MA Reportables

Rational green plasticisers

- Company X had 5 “green” synthons
- These could be combined in many ways to give 1000’s of possible plasticiser molecules for some common polymers
- Too many to synthesise and test
- So calculated HSP, MPt, VP, etc. of each molecule
 - Took 5min from a list of SMILES
- Rejected all with low MPt or high VP
- For each polymer could identify lowest HSP distance
 - Could then synthesise, test ... and patent!

In miniature

- The best plasticiser for PLA?

Table of plasticisers created (mostly) automatically from HSPiP plus one extra. The phthalates are great but can't be used. The citrates are green but are useless. A polyester is ideal.

The screenshot displays the TURI Plasticiser software interface. The main window shows a table of plasticisers with columns for No., Solvent, δD , δP , δH , Score, RED, and MVol. The table lists various plasticisers, with Oligo Polyester highlighted as the best match for PLA. A 3D plot on the right shows a green sphere representing the plasticiser's properties in a space defined by δD , δH , and δP .

No.	Solvent	δD	δP	δH	Score	RED	MVol
9999	Oligo Polyester	17.5	9	6	-	0.41	-
221	Dibutyl Phthalate	17.8	8.6	4.1	-	0.55	267.2
258	Diethyl Phthalate	17.6	9.6	4.5	-	0.58	199.7
275	Dihexyl Phthalate	17	7.6	3.6	-	0.76	332.3
305	Diethylhexyl Phthalate (Di...	16.6	7	3.1	-	0.92	398.5
1219	Acetyl Triethyl Citrate	16.6	3.5	8.6	-	1.02	279.9
1220	Tri-n-Butyl Citrate	16.6	3.8	10.1	-	1.08	345.5
1137	Tri-n-Butyl Acetyl Citrate	16.7	2.5	7.4	-	1.10	384.3
313	Ditridecyl Phthalate	16.6	5.4	1.9	-	1.15	558.3
1218	Triethyl Citrate	16.5	4.9	12	-	1.19	243

No.	Polymer	δD	δP	δH	Radius	Comment	Score	Rating	F
610	Nylon 66	17.4	9.9	14.6	8	Instant guide	-	1	-
611	PET	18.2	6.4	6.6	8	Instant guide	-	1	-
612	Epoxy	17.4	10.5	9	8	Instant guide	-	1	-
613	Polyvinylbutyral	18.6	4.4	13	8	Instant guide	-	1	-
614	Polyvinylidene fluoride (PVF)	17	12.1	10.2	8	Instant guide	-	1	-
615	Polyphenyleneoxide (PPO)	17.9	3.1	8.5	8	Instant guide	-	1	-
616	Polyurethane (PU)	18.1	9.3	4.5	8	Instant guide	-	1	-
617	Polysulphone	16	6	6.6	8	Instant guide	-	1	-
618	Polysilicone	17.2	3	3	8	Instant guide	-	1	-
619	Polyethersulfone	19	11	8	8	Instant guide	-	1	-
620	Polyoxymethylene (PON)	17.2	9.2	9.8	8	Instant guide	-	1	-
621	Polyvinylpyrrolidone (PVP)	18.1	10	18	8	Instant guide	-	1	-
622	Cyclic Olefin Copolymer (COC)	18	3	2	8	Instant guide	-	1	-
623	Polyethylene oxide (PEO, P...	17	10	5	8	Instant guide	-	1	-
624	Polypropylene oxide (PPO, ...	16.5	9	7	8	Instant guide	-	1	-
625	Polyvinylalcohol (PVOH)	15	17.2	17.8	8	Instant guide	-	1	-
626	Polyactic acid (PLA)	18.5	8	7	8	Instant guide	-	1	-

HSP and particles

- Illustrated with CNT
- Shake with test solvents and score from “Happy” (on the left) to “Unhappy” on the right
- Can calculate HSP of CNT ...
- ... then predict optimized practical blends
 - e.g. CNT are easily dispersed in PLA

Works for
nanoclays too.
Working with
U.Mass Lowell!



CNT “happiness” – photos courtesy Dr S Detriche, U. Namur

Diffusion for safety, environment & practical packaging

- Diffusion across a polymer barrier (gloves, environmental membrane, protection suit, packaging of food or chemicals) controlled by
 - Polymer (it is what it is)
 - Chemical shape/size (it is what it is)
 - Concentration gradient
 - So a high solubility in the top 1nm means a large concentration gradient which means faster diffusion
 - So can predict glove safety, chemical protection, flavour scalping, shipping containers, consumer packaging via HSP

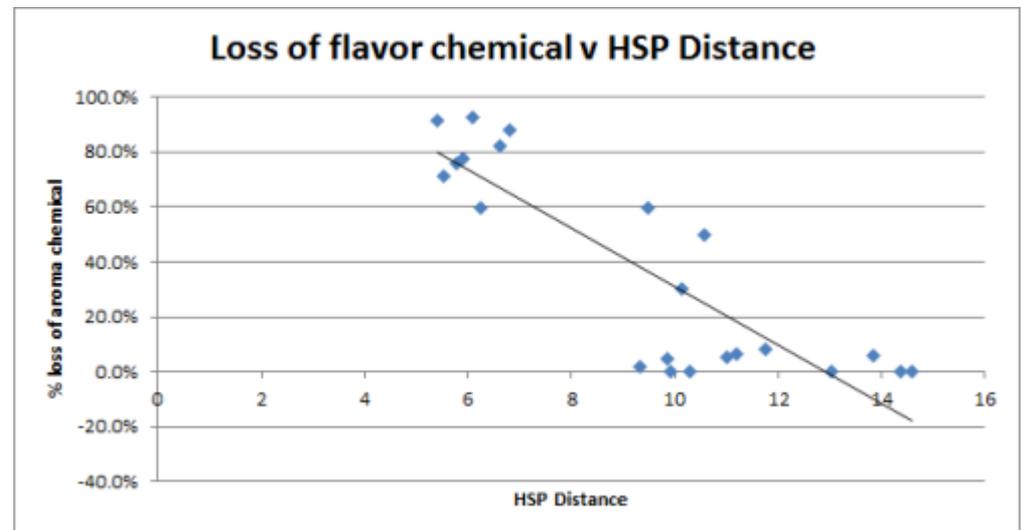
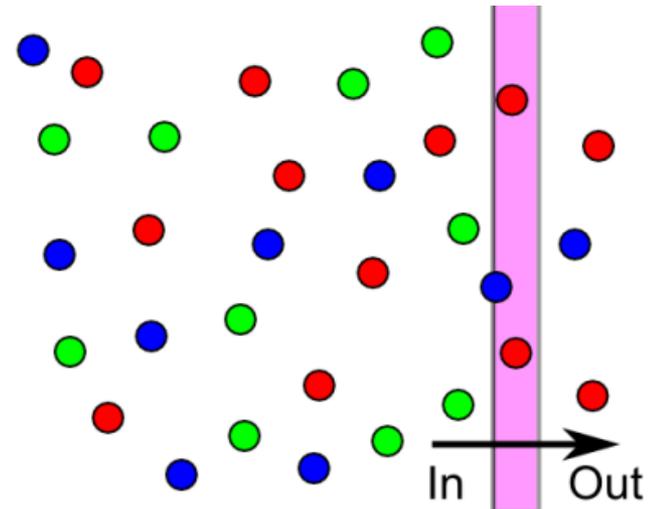
A flavour scalping example

A new juice concept was great, but lost many of its flavour molecules after a few weeks.

The “red” molecules are more soluble (lower HSP Distance) than the “green” ones so you lose more of the red flavour through the packaging

Real data of 20 different flavour molecules in the juice.

All the ones with small HSP Distances were disappearing through the walls



A shipping container example

- Question: “Can we ship this chemical in an HDPE ‘balloon’ inside a container?”
- Answer: “The HSP Distance is too small so it won’t work – though the molecule is large so diffusion will be slow”
- Response: “You’re wrong – it turns out we ship this stuff with no problem”
- Answer: “Check. I guarantee you’re wrong”
- Response: “Ah, we can ship OK but the guys at the other end hate it because the container stinks of the chemical”

Your formulations too

- HSPiP does a great job with safety-specific questions
- But it is also used for many other reasons all around the world
 - Large corporations, Small companies, Single consultants
 - Polymers, Drug delivery, Environmental, Cosmetics formulations, Organophotovoltaics, Paints, Coatings, ...

What now?

- There's a resource pack containing this PPT, an HSP Excel workbook, a list of links, including to short HSPiP videos on YouTube
- I am actively working with TURI to offer help, guidance, support on HSPiP for your community
- I'm happy to answer your questions by email, telecon or weblink
- And now to your webinar questions ...