Determination of Solubility Parameters using Inverse Gas Chromatography

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Overview

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- Inverse Gas Chromatography
- Solubility Parameter
- Hansen Solubility Parameter
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Introduction

Spectroscopic techniques will normally yield **analytical information** on solid state materials such as **what is present, where is it present and how much is present**. This data contain little, if any, thermodynamic information.

The best techniques for determining **surface thermodynamic** and related **physicochemical information** about solid surfaces use vapour phase molecules as molecular probes for studying, in detail, gas-solid interactions – sorption techniques.

Advantages

Techniques that use vapour-phase probes offer a number of significant **advantages** over traditional analytical or spectroscopic approaches including:

- samples can be studied under **real world conditions** – ambient temperature and pressure;
- probe molecules can be chosen with chemical properties that are appropriate or relevant to the information required or problem to be addressed and may be site specific
- both **bulk and surface properties** can be elucidated as molecular probes can diffuse into materials giving an insight into internal molecular structure;
- vapour-phase molecular probes are **extremely sensitive** probes for determining the surface chemistry at sub-monolayer coverages for particulate materials;
- typically, both **kinetic and equilibrium thermodynamic data** can be obtained using molecular probe techniques.

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Sorption Instruments

The two main characterization techniques in current usage that use molecular vapour sorption approaches for characterizing solid state materials are **dynamic vapour sorption (DVS)** and **inverse gas chromatography (iGC)**.

Surface Measurement Systems (SMS) is the World Leader Company in Sorption Science. **SMS** produces the first commercial iGC system and it is the lead company in dynamic sorption technique.

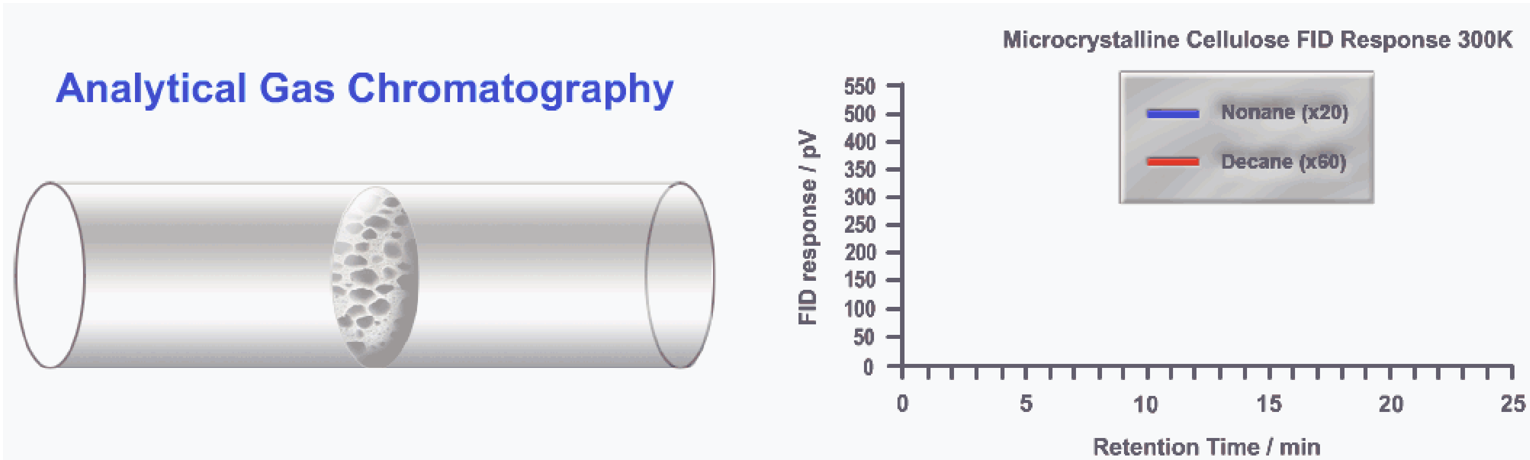
Inverse Gas Chromatography

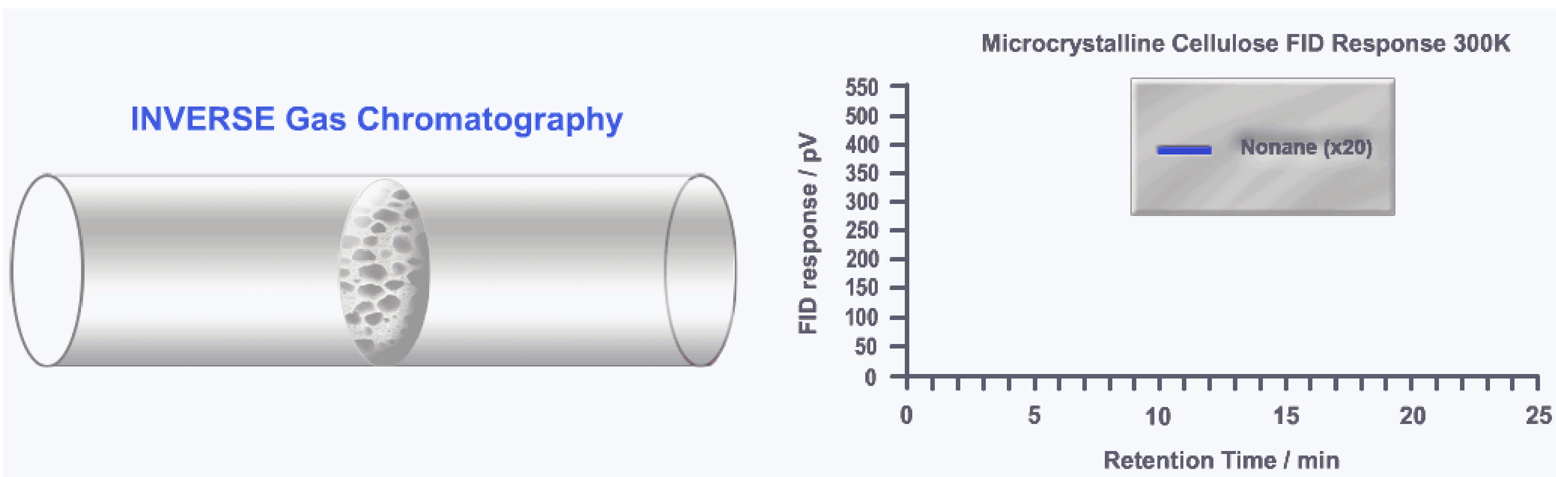
Introduction

Inverse Gas Chromatography (IGC) principles*: 1st developed in 1960's.

The **iGC-SEA** system is the first commercial inverse Gas Chromatography technique. It is specially designed to determine the surface energy heterogeneity but nevertheless suitable to measure different surface and bulk properties of solid materials such as **Adsorption isotherms**, **Heat of sorption**, **Glass Transition Temperature**, **Solubility Parameters** and so on.

IGC Principles





Animation by L. Teng, Surface Measurement Systems

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iGC-SEA Introduction

- **Gas phase injection** (like Headspace) - 12 vapor reservoirs (50 ml)
- **Carrier gas** is helium
- 2 column position oven design: **20 to 150 ˚C**
- **Background Humidity Controller**
- Flame Ionization Detector (FID)
- **User Friendly** Control and Analysis **Software**

Carbon fiber | cotton | hair | granules | powder | medical metal implants

Safety Features:
Hydrogen Leak & Organic Vapor Leak Detectors

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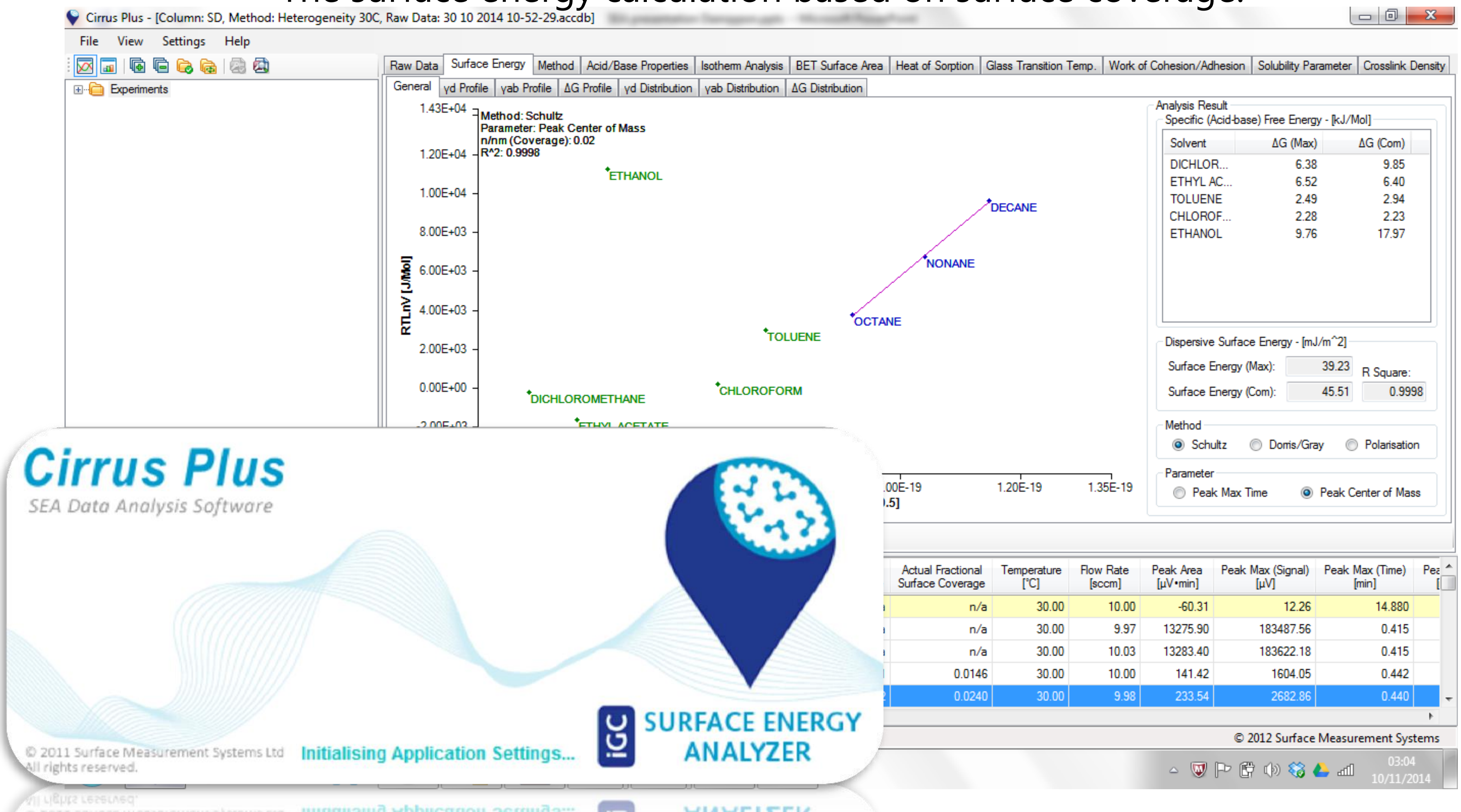
SEA Calculation theories

Unique Analysis Software (Cirrus Plus) for the quick sample analysis, which contains the all methods and theories.

The surface energy calculation based on surface coverage.



Properties measured by IGC-SEA

The IGC-SEA provides unique access to the following physico-chemical properties of a wide range of solid materials in a controlled humidity environment:

- Dispersive and Polar Surface Energies
- Heats and Entropies of Adsorption
- Acid/Base Interactions
- BET Specific Surface Area
- Phase Transitions
- Sorption Isotherms
- Permeability, Solubility and Diffusion
- Competitive (Multicomponent) Adsorption
- Thermodynamic Work of Cohesion and Adhesion
- Surface Energy heterogeneity mapping
- Constantly extend the applications – future applications e.g. Chemisorption

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iGC Principle

Pack a column with the sample of interest

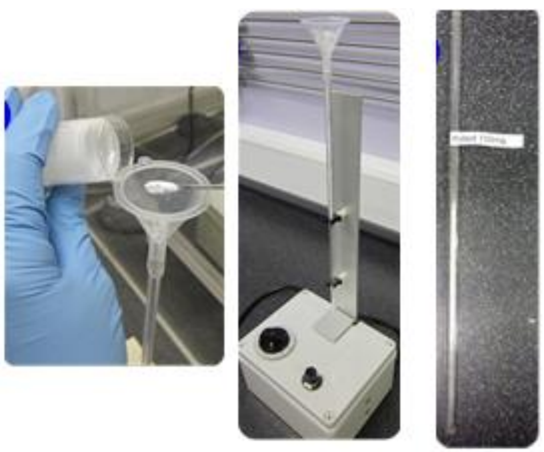
Select probes

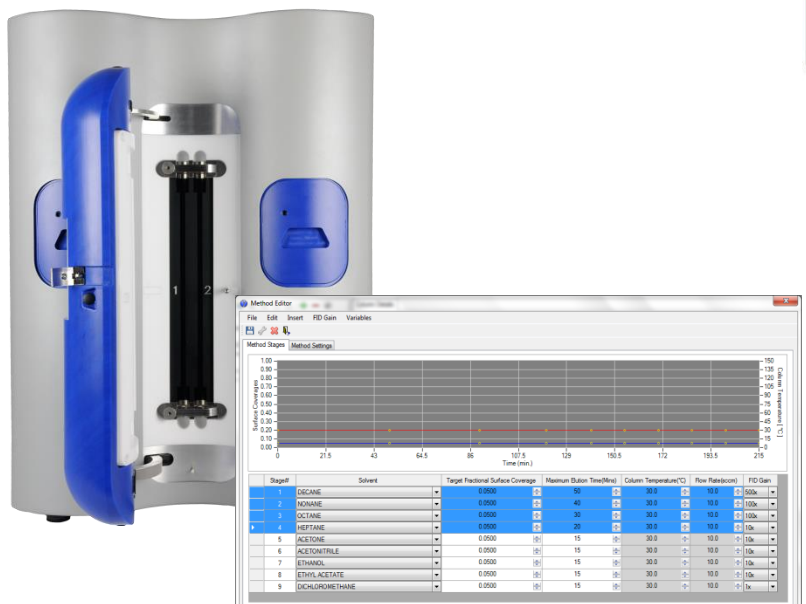
Non-polar solvent for the dispersive interaction

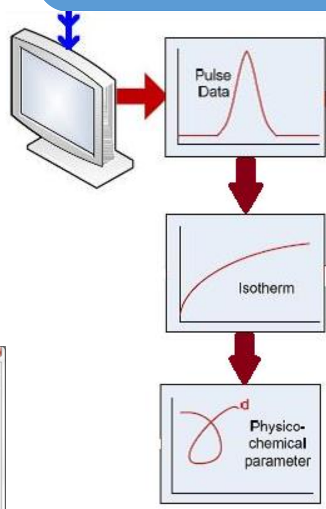
Polar solvents for the specific interactions

Inject them at infinite and/or finite dilution

From the retention time the different physico-chemical properties can be determined







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Benefits of iGC-SEA

- 2 column position oven design - two sample can be prepared and can be run sequentially, automatically
- No need for outgassing facilities, since this will be achieved by conditioning the sample inside the column and flashing it with inert gas
- Easier column packing procedure due to the column is straight
- Precise and wide range of injectable amounts – vapour phase injection not liquid
- Automatic injection system and automatic calculation
- Excellent reproducibility (RSD 1% for surface energy)

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Solubility Parameter

The Solubility Parameter is directly related to the cohesion energy density and therefore stability of a material:

$$\delta = \left(\frac{\Delta E_{vap}}{V_m} \right)^{1/2} = \left(\frac{\Delta H_{vap} - RT}{V_m} \right)^{1/2} = CED^{1/2}$$

Applications:

- Drug delivery
- Formulation
- Storage stability
- Coatings
- Polymer compatibility
- Optimising solvent selection for nanoparticle preparation

Adamska & Voelkel (2005) Inverse gas chromatographic determination of solubility parameters of excipients. Int. J. Pharm., 304, p11-17.

Solubility Parameter

Application of the Hildebrandt theory in combination with Flory-Huggins concept

- Determination of the Activity Coefficient Ώ from the ret.-volume V_N

$$\ln \Omega = \ln\left[\frac{273.15 \cdot R}{P_0 \cdot MW \cdot V_N} \cdot 10^6\right] - \frac{P_0 \cdot (B_{11} - V_m)}{R \cdot T \cdot 10^6}$$

- Calculation of the Flory-Huggins interaction parameter χ

$$\chi = \ln \Omega + \ln\left[\frac{D_1}{D_2}\right] - \left[1 - \left(\frac{V_{m1}}{V_{m2}}\right)\right]$$

Solubility Parameter

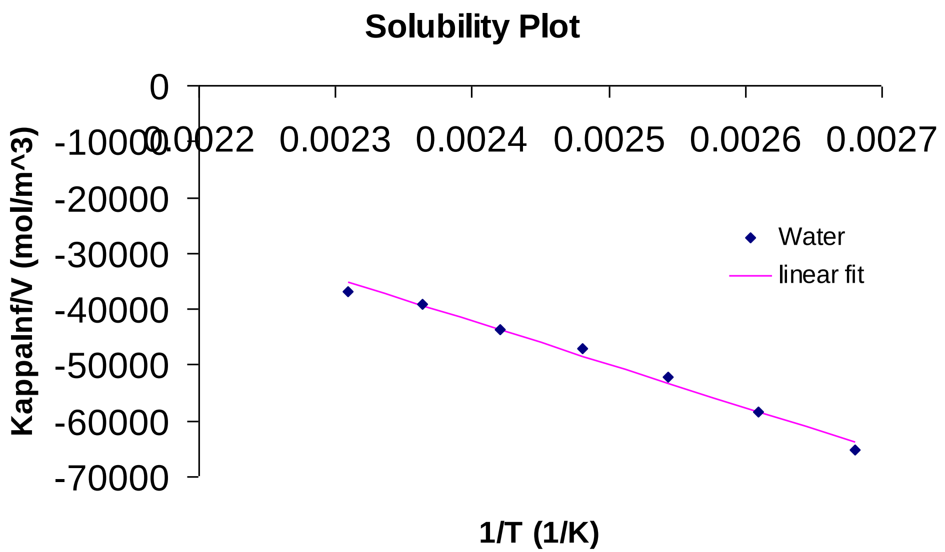
Variation of probe molecule or temperature

➢ **Guilett Approach:**

$$\frac{\delta_1^2}{RT} - \frac{\chi}{V_1} = \left(\frac{2\delta_2}{RT}\right)\cdot\delta_1 - \left(\frac{\delta_2^2}{RT} - \frac{\chi_S}{V_1}\right)$$

➢ **Benczedi Approach:**

$$\delta_2 = \delta_1 - \left[R\cdot\frac{\partial(\chi^\infty/V_1)}{\partial(1/T)}\right]^{1/2}$$



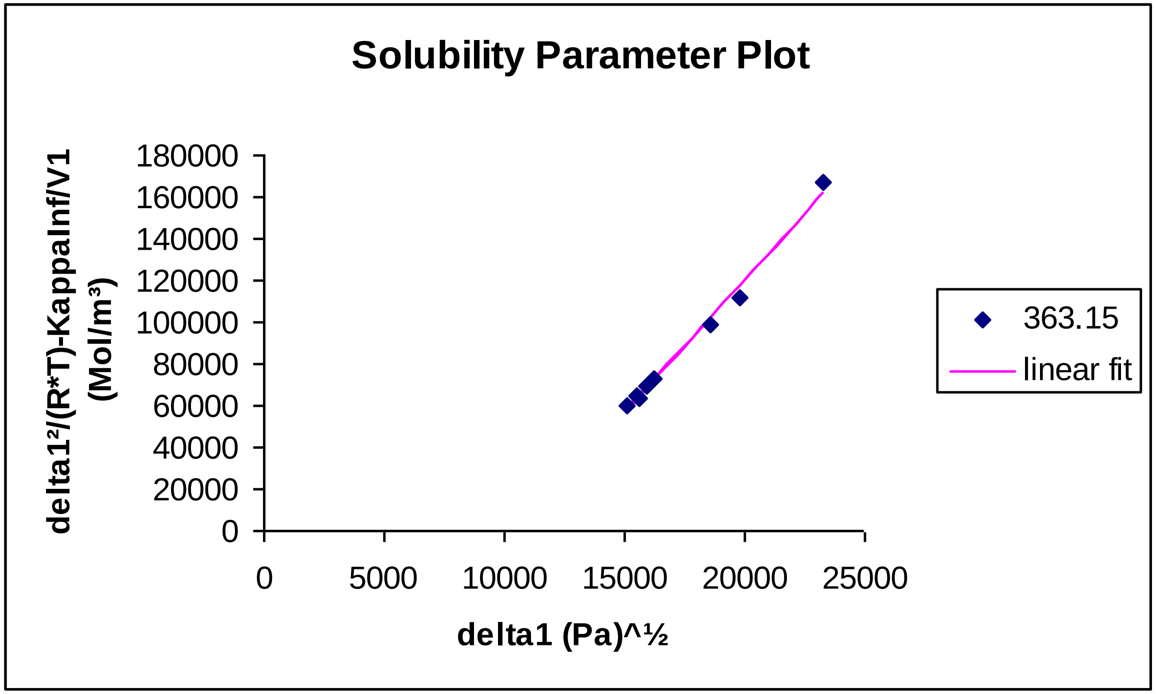
Solubility Parameter for Starch:

22.6 MPa$^{1/2}$

(measured between 373 K and 433 K)

Solubility Parameter

Ref.: SMS IGC Application Note 218



"Hildebrandt" Sol. Parameter for PMMA:

19.08 MPa$^{1/2}$

(measured at 363 K with Undecane, Decane, Nonane, Octane, Heptane, Dichloromethane, 1-Butanol, Ethyl Acetate, 1,4-Dioxane)

Literature value: ***17.4 – 21.3 MPa$^{1/2}$***

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Hansen Solubility Parameters

$$\delta_T^2 = \delta_d^2 + \delta_p^2 + \delta_h^2$$

Dispersive component:
Solvents: Alkanes

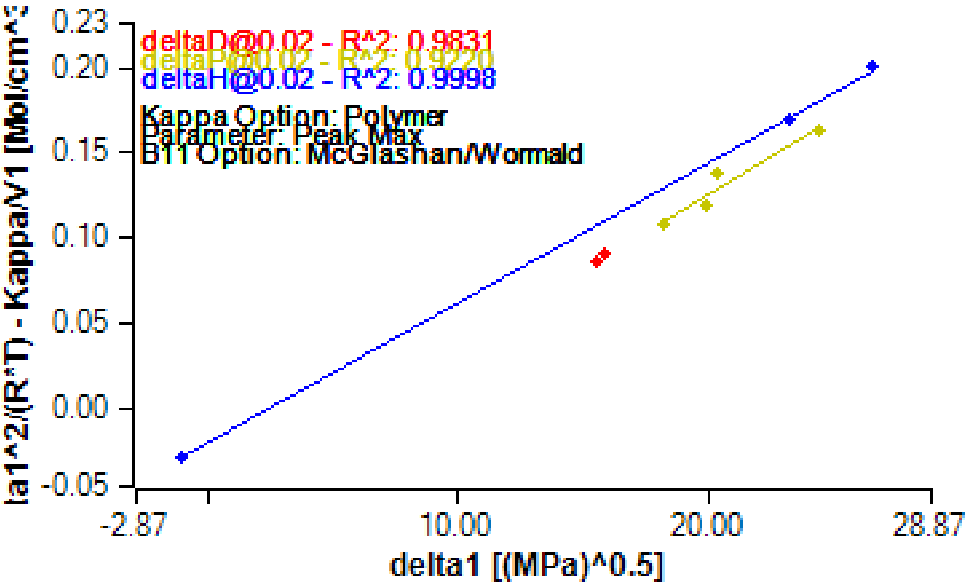
$$\delta_d = \frac{slope_{alkanes} \cdot R \cdot T}{2}$$

Polar component:
Solvents: Aromatic hydrocarbons Ketones, Nitropropane

$$\delta_p = \frac{\left(slope_{polar} - slope_{alkanes}\right) \cdot R \cdot T}{2}$$

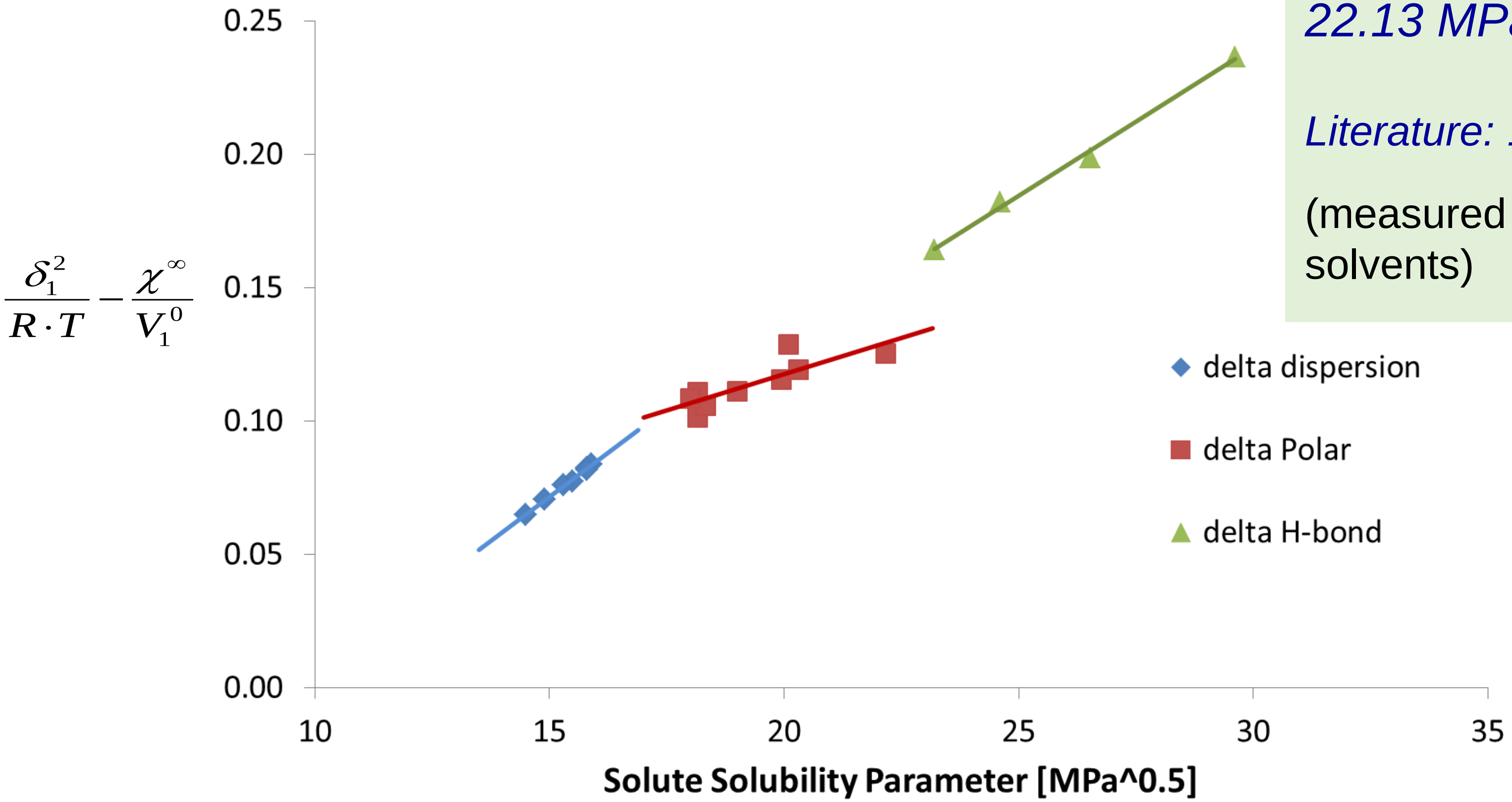
Hydrogen Bonding component:
Solvents: Alcohols, Pyridine

$$\delta_h = \frac{\left(slope_{alcohols} - slope_{alkanes}\right) \cdot R \cdot T}{2}$$



Hansen Solubility Parameters

$$\delta_T^2 = \delta_d^2 + \delta_p^2 + \delta_h^2$$



"Hansen" Total Sol. Parameter for Polymer X:

22.13 MPa$^{1/2}$

Literature: 19.30 MPa$^{1/2}$

(measured at 343 K with 32 solvents)

Solubility Parameter

Relationship between oral absorption in humans and solubility parameters

'Solubility parameter and oral absorption'

Martini, L. et al, Europ. J. Pharm. Biopharm. 48 (1999), 259-263

Correlation between release rate of chlorohexidine from ethylcellulose films and solubility parameters

'Casting solvent controlled release of chlorhexidine from ethylcellulose films prepared by solvent evaporation'

Jones, D. et al, Int. J. Pharm. 114 (1995), 257-261

SMS Ref.: Application Note 205 IGC Solubility Starch

SMS User's Publication: Journal of Chromatography A, 1216 (2009) 1551–1566, A. Voelkel, Inverse gas chromatography as a source of physiochemical data

K. Adamska∗, A. Voelkel, A. Berlinska; *The solubility parameter for* ***biomedical polymers*** *- Application of inverse gas chromatography*, Journal of Pharmaceutical and Biomedical Analysis 127 (2016) 202

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Thank you for your attention!





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Q&A

Any questions or thoughts?