Kinetic modeling using chemo-informatics: Genesys

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http://www.lct.ugent.be
Kinetic models grow larger and larger

Genesys: computer generated kinetic models

Automatic calculation of:
- Species thermochemistry
- Elementary reaction kinetics

http://www.lct.ugent.be/
Reaction network generation

Molecules
- Unique Representation
- Thermo-dynamics

Reaction families
- Reaction Identification
- Kinetic Parameters

Reaction rules
- Kinetic model enlargement
- Termination criterion
Graph theory and algorithms can be applied: main methods for chemistry apps:
- Sub-graph matching ~ functional group query
- Equivalence test ~ structure database query

Defining sub-molecular patterns:
SMARTS (SMILES Arbitrary Target Specification)
Don’t re-invent the wheel: chemo-informatics

Andrew Dalke’s EuroQSAR 2008 Poster
(http://www.dalkescientific.com/)

Multiple ligands alignment within 3D field potential from Qmol LLC.
Genesys: integration of CDK

**CDK Library Tools**
- species input/output parsing and generation (InChI, SMILES, etc...)
- substructure searching
- species internal representation
- species, reaction visualization

**Genesys Code**
- reaction execution
- reaction family implementation
- network generation
- rule-based termination
- thermodynamic properties generation
- kinetic parameters generation

#Chemistry Development Kit
Reaction families in Genesys

- Add chemistry **you** know that is relevant;
- Constrain reaction families as much as possible

E.g. “C-H β scission in presence of double bond in γ position”

Single bond between radical C and H-bearing C

$sp^2$ C’s in double bond, not sp

Radical C not part of ring
Defining reaction families: pattern, recipe, constraints

Submolecular pattern:

Reactive center:

Molecule Constraints:

MINIMUM Carbon COUNT 5
MAXIMUM Carbon COUNT 10
TOTAL NUMBER OF SINGLE ELECTRONS 1

SMARTS:

\[ \text{C=C-C(H)-[C;v3]} \]

\[ \begin{align*}
\text{A} & : [\text{C;v3}]-\text{C(H)}-\text{C}=&
\text{C} \\
\text{B} & : \text{H}-\text{C([C;v3])}-\text{C}=&
\text{C} \\
\text{C} & : \text{C(C=C)(H)}-\text{[C;v3]} \\
\end{align*} \]

RECIPE:

(1) BREAK BOND B,C
(2) INCREASE BOND A,C
(3) LOSE RADICAL A
(4) GAIN RADICAL B
Ideal gas TD Properties: Benson Additivity

2-methylnonane

Atoms in large molecules

Group additivity

Atoms in small molecules with similar surroundings

Group definition based on surroundings (ligands)

Additivity:

\[
\text{\begin{align*}
\text{Additivity:} & = 1 \text{ green atom} + 6 \text{ blue atoms} + 3 \text{ orange atoms} \\
\text{2-methylnonane} & = 
\end{align*}}
\]
Filling the Benson Database

Nature of GAVs, ca. 1000 unique groups

NETWORK GENERATION
Network generation: HMPA

Define reaction:

HMPA

Generated species
BUILDING KINETIC MODELS
Building kinetic models: Kinetic group additivity

**Arrhenius equation**

\[ k = A e^{\frac{E_a}{RT}} \]

**Group additivity for Arrhenius parameters**

\[ E_a(T) = E_{a,\text{ref}}(T) + \sum_{i=1}^{3} \Delta GAV_{E_a}^\circ(C_i) \]

\[ \log A(T) = \log \tilde{A}_{\text{ref}}(T) + \sum_{i=1}^{3} \Delta GAV^\circ(C_i) + \log n_e \]

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Saeys et al. 2004, AIChE J.
Alkylsulfide thermal decomposition

Chemistry knowledge:
A.G. Vandeputte, The thermochemistry and Decomposition Mechanism of Organosulfur and Organophosphorus Compounds, 2012 (Ph.D)

Kinetic data:
Hydrocarbon reaction families:
  Hydrogen abstractions: Sabbe et al. PCCP, 2010, 12, 1278–1298

Sulfur reaction families:
  Hydrogen abstractions : Vandeputte et al. PCCP, 2012;14(37):12773-93
  Homolytic substitutions: Vandeputte et al. 2012 (Ph.D)

Generated model:
  3612 reactions
  151 species
Ethyl-methyl-sulfide pyrolysis: validation

[Graphs showing mole fraction of ethyl methyl sulfide and ethylene at different temperatures (903K, 973K, 943K, 1013K).]
EMS pyrolysis: quantitative analysis

EMS conversion: 14%
Temperature: 1013K
Residence time: 0.2s
Conclusion

- **Genesys**: automatic reaction network generation framework for quantitative models
  - **Integrated** with open-source chemo-informatics library (CDK)
  - **Generally** applicable:
    - Support for many elements
    - Support for many chemistries
  - Quantitative structure – property relationships **easily implementable**
    - Ideal Gas TD Properties
    - Kinetic expressions for elementary reactions
LCT @ UGent:
- Steven Pyl, Carl Schietekat, Thomas Dijkmans, Ruben De Bruycker
- Aäron Vandeputte, Maarten Sabbe, Ruben Van de Vijver

Funding:
- Long Term Structural Methusalem Funding by the Flemish Government
- Fund for Scientific Research - Flanders
THANK YOU!