SUPPORTING INFORMATION

Parametrization of Nanoparticles: Development of Full-particle Nanodescriptors

Kaido Tämm,a\* Lauri Sikk,a Jaanus Burk,a Robert Rallo,b Suman Pokhrel,c Lutz Mädler,c

Janeck J Scott-Fordsmand,d Peeter Burk,a Tarmo Tamme

*aInstitute of Chemistry, University of Tartu, Ravila 14a, Tartu 50411, Estonia*

*bDept Engn Informat & Matemat. Universitat Rovira i Virgili, Av. Paisos Catalans 26, Tarragona 43007, Spain*

*cFoundation Institute of Materials Science (IWT), Department of Production Engineering, University of Bremen, Germany*

*dAarhus University, Dept Bioscience, Vejlsøvej 25, PO Box 314, 8600 Silkeborg, Denmark*

*eInstitute of Technology, University of Tartu, Nooruse 1, Tartu 50411, Estonia*

\*Corresponding author: e-mail: karu@ut.ee

**Supporting Information starts here:**

**Table 1.** Formulas for calculating nanodescriptors for Metal Oxide nanoparticles.

|  |  |
| --- | --- |
| **GROUP 1: CONSTITUTIONAL DESCRIPTORS** |  |
| Total number of atoms in nanoparticle. | N |
| Total number of atoms in surface region of nanoparticle. | NC |
| Total number of atoms in shell region of nanoparticle. | NS |
| Total number of metal atoms in nanoparticle. | NM |
| Total number of metal atoms in surface region of nanoparticle. | NM,C |
| Total number of metal atoms in shell region of nanoparticle. | NM,S |
| Total number of oxygen atoms in nanoparticle. | NO |
| Total number of oxygen atoms in surface region of nanoparticle. | NO,C |
| Total number of oxygen atoms in shell region of nanoparticle. | NO,S |
| **GROUP 2: POTENTIAL ENERGY DESCRIPTORS** |  |
| Average potential energy of all atoms in nanoparticle in electron volts. | EP/N, where EP is sum of potential energy of all atoms in nanoparticle |
| Average potential energy of atoms in surface region of nanoparticle in electron volts. | EP,C/NC, where EP,C is sum of potential energy of atoms in surface region |
| Average potential energy of atoms in shell region of nanoparticle in electron volts. | EP,S/NS, where EP,S is sum of potential energy of atoms in shell region |
| Average potential energy of metal atoms in nanoparticle in electron volts. | EP,M/NM, where EP,M is sum of potential energy of metal atoms in nanoparticle |
| Average potential energy of metal atoms in surface region of nanoparticle in electron volts. | EP,M,C/NM,C, where EP,M,C is sum of potential energy of metal atoms in surface region |
| Average potential energy of metal atoms in shell region of nanoparticle in electron volts. | EP,M,S/NM,S, where EP,M,S is sum of potential energy of metal atoms in shell region |
| Average potential energy of oxygen atoms in nanoparticle in electron volts. | EP,O/NO, where EP,O is sum of potential energy of oxygen atoms in nanoparticle |
| Average potential energy of oxygen atoms in surface region of nanoparticle in electron volts. | EP,O,C/NO,C, where EP,O,C is sum of potential energy of oxygen atoms in surface region |
| Average potential energy of oxygen atoms in shell region of nanoparticle in electron volts. | EP,O,C/NO,S, where EP,O,C is sum of potential energy of oxygen atoms in shell region |
| **GROUP 3: TOPOLOGY DESCRIPTORS** | *Coordination number of each individual atom is defined as the count of atoms which lie in the radius R=1.2\*(RM+RO), RM and RO are ionic radii of metal and oxygen atoms.* |
| Average coordination number of all atoms in nanoparticle. | C/N, where C is the sum of coordination numbers of all atoms in nanoparticle |
| Average coordination number of atoms in surface region of nanoparticle. | CC/NC, where CC is the sum of coordination numbers of all atoms in surface region |
| Average coordination number of atoms in shell region of nanoparticle. | CS/NC, where CS is the sum of coordination numbers of all atoms in surface region |
| Average coordination number of metal atoms in nanoparticle. | CM/NC, where CM is the sum of coordination numbers of all metal atoms in nanoparticle |
| Average coordination number of metal atoms in surface region of nanoparticle. | CM,C/NC, where CM,C is the sum of coordination numbers of all metal atoms in surface region |
| Average coordination number of metal atoms in shell region of nanoparticle. | CM,S/NC, where CM,S is the sum of coordination numbers of all metal atoms in shell region |
| Average coordination number of oxygen atoms in nanoparticle. | CO/NC, where CO is the sum of coordination numbers of all oxygen atoms in nanoparticle |
| Average coordination number of oxygen atoms in surface region of nanoparticle. | CO,C/NC, where CO,C is the sum of coordination numbers of all oxygen atoms in surface region |
| Average coordination number of oxygen atoms in shell region of nanoparticle in. | CO,S/NC, where CO,S is the sum of coordination numbers of all oxygen atoms in shell region |
| **GROUP 4: SIZE DESCRIPTORS** |  |
| Diameter of the nanoparticle in Å. | D |
| Surface area of the nanoparticle in Å2. | 4πr2, where r is the radius of nanoparticle |
| Volume of the nanoparticle in Å3. | 4πr3/3, where r is the radius of nanoparticle |
| **GROUP 5: LATTICE ENERGY DESCRIPTORS** |  |
| Lattice energy of nanoparticle in electron volts. | (nO+nM)EP/N, where nO and nM are number of oxygen and metal atoms in metal oxide formula (e.g. 3 and 2 for Fe2O3) |
| Difference of the lattice energies of nanoparticle and infinite crystal. | EL,I- EL, where EL,I- is the lattice energy calculated for infinite crystal (periodic calculation of 8 unit cells), EL is the lattice energy of nanoparticle |
| Lattice energy of nanoparticle divided by the diameter of nanoparticle. | EL/A, where EL is the lattice energy of nanoparticle and D is the diameter of nanoparticle |
| Lattice energy of nanoparticle per unit surface area. | EL/A, where EL is the lattice energy of nanoparticle and A is the area of nanoparticle |
| Lattice energy of nanoparticle per unit volume. | EL/A, where EL is the lattice energy of nanoparticle and V is the volume of nanoparticle |

**QNAR model development**

The model development was carried out using the CODESSA PRO software.(www.codessa-pro.com) In the first step of feature selection, the most significant nanodescriptors were chosen from the pool of 35 descriptors according to the following criteria: correlation improvement cutoff – 0.02, max *R2* for orthogonal scales – 0.1, max *R2* for collinear scales – 0.6 For constructing two-parameter equations, pairwise selection was performed according to the criteria: inter-correlation coefficient in the pair below threshold (0.01), significant correlation with endpoint in terms of correlation coefficient and t-test.

The validation of sample model making use of the novel nanodescriptors was constructed based on the 17 metal oxide nanoparticles already modeled by Puzyn*, et. al*.16(main paper) Surface-modified particles and mixed oxides were not considered here, as these were out of scope of the present study. All of the particles were constructed as described in the methodology and the respective nanodescriptor values were calculated according to the sizes of the particles. The model was constructed using the best-multilinear algorithm (BMLR).

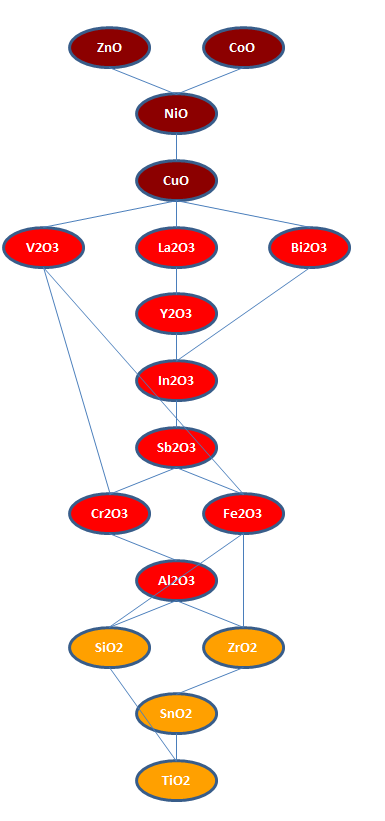
The resulting two-parameter model (*Sample 1*, Table 2, Figure 1) had the following equation:

*log(1****/****EC50) = 3.82 + 0.07D1 - 0.05D2,*  (1)

where *D1* is the descriptor “Average potential energy of atoms in shell region of nanoparticle” and *D2* is the “Average potential energy of oxygen atoms in surface region of nanoparticle”, both given in electron volts. The statistical parameters of the model were found to be: squared correlation coefficient (*R2 = 0.87*); squared cross validated correlation coefficient (*R2cv = 0.81*); Fisher criterion (*F = 45.26*); Squared standard deviation (*s2 =0.04*). The principal descriptor here was found to be *D1*, which by itself was capable of accounting for most of the variability in the dataset (one-parameter model with *R2 = 0.83*). However, the two-parameter model, while only slightly higher correlating, was found to be more stable.

**Table 2.** Experimental and predicted *log(1****/****EC50)* values of nanoparticles, calculated nanodescriptors and diameters for *Sample 1.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | ***log(1/EC50)*** | | **Nanodescriptors** | | **NP size** |
| **NP** | **Exp.** | **Pred.** | **D1 (eV)** | **D2 (eV)** | **Diameter (nm)** |
| Al2O3 | 2.49 | 2.49 | -32.79 | -20.8 | 31 |
| Bi2O3 | 2.82 | 3.01 | -17.04 | -8.36 | 51 |
| CoO | 3.51 | 3.37 | -19.83 | -20.14 | 20 |
| Cr2O3 | 2.51 | 2.68 | -30.37 | -21.09 | 20 |
| CuO | 3.2 | 3.34 | -21.25 | -21.6 | 48 |
| Fe2O3 | 2.29 | 2.71 | -29.64 | -20.71 | 20 |
| In2O3 | 2.81 | 2.75 | -27.88 | -18.94 | 59.6 |
| La2O3 | 2.87 | 2.77 | -12.12 | 4.24 | 24.6 |
| NiO | 3.45 | 3.37 | -19.92 | -20.33 | 20 |
| Sb2O3 | 2.64 | 2.74 | -28.04 | -18.97 | 20 |
| SiO2 | 2.2 | 1.96 | -41.98 | -23.11 | 20 |
| SnO2 | 2.01 | 2.11 | -37.23 | -19.27 | 21 |
| ZnO | 3.45 | 3.38 | -19.36 | -19.7 | 21 |
| ZrO2 | 2.15 | 2.22 | -32.16 | -14.06 | 25 |
| TiO2 | 1.74 | 1.77 | -43.31 | -21.05 | 15 |
| V2O3 | 3.14 | 2.72 | -28.6 | -19.47 | 20 |
| Y2O3 | 2.87 | 2.75 | -27.19 | -18 | 32.7 |



**Figure 1. A:** Plot of observed *vs.* predicted *log(1/EC50)* values of metal oxide nanoparticles for *Sample 1.B: Ranks of the same values showing the overall oxidation stage of the metals ion*  *(Rank correlation of 0.9)*