Using Equations of State for Modeling Complex Molecules

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50 years ago, the well-known Peng-Robinson equation of state paved the way for modeling the thermodynamic properties of non-ideal gases and liquids with a level of accuracy suitable for use in engineering applications. To this day, it is considered the gold standard for modeling hydrocarbon molecules.

25 years later, PC-SAFT (Perturbed-Chain Statistical Associating Fluid Theory) was proposed aiming at modeling associating compounds and polymers. Like the Peng-Robinson Equation of State, PC-SAFT accounts for both repulsion and van-der-Waals attraction of molecules. In addition to that, it takes advantage of the physical background of the original SAFT model and its ability to describe the formation of hydrogen bonds in associating systems. To model long-chain molecules, we replaced the hard-sphere reference in the attraction term by a hard-chain reference. The latter did not only remarkably improve the modeling results for polymers but for non-spherical molecules in general and is widely used today. Since then, PC-SAFT was further extended to account for the impact of polarity (PCP-SAFT), to describe electrolytes (ePC-SAFT), polymeric networks, and even polyelectrolytes (pePC-SAFT).

These model developments allowed for also extending the range of applications and this will be the main focus of this talk. The journey started from modeling phase equilibria related to the production, purification and recycling of polymers, which was then extended to model the swelling of polymer networks and hydrogels. The latter are swollen by water or aqueous mixtures of biological relevant molecules which brought us to modeling a whole bunch of those molecules, such as organic osmolytes, amino acids or pharmaceutical compounds. The talk will illustrate applications of PC-SAFT to those systems covering all types of phase equilibria (VLE, LLE, and SLE) and even reaction equilibria. Accounting for activity coefficients using PC-SAFT for example allowed predicting the influence of solvent(s) and electrolytes on both yield and kinetics of (bio)chemical reactions.

Recent research of our group focuses on using PC-SAFT as an in-silico tool for process and product design related to the production, purification, and formulation of active pharmaceutical ingredients (APIs). APIs usually are crystalline solids and only very little soluble in aqueous media. To improve their bioavailability, APIs can be stabilized in their amorphous form in complex mixtures based on lipids or polymers, so-called formulations. The talk illustrates that thermodynamic predictions based on PC-SAFT can remarkably reduce the experimental effort for identify promising excipients, even including surfactants, and allow for reliable predictions of formulation stability during production and storage and of their release behavior in the human body.