Modeling of the moisture sorption kinetics and humidity-induced collapse for freeze-dried products

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Freeze-drying/lyophilization is an essential technology for the production of stable dried pharmaceuticals with longer shelf life. Freeze-drying produces porous product with a large surface area and high hygroscopicity. Moisture sorption to freeze-dried products remains a problem through the processing and during long-term storage. It would be useful, for example, if a model gives possible waiting periods from the end of drying to the packaging, or shelf-life of a product in a package where moisture leakage cannot be completely avoided. Moisture sorption is governed by the glass-rubber transition of the freeze-dried matrix. Since this transition relates to the temperature and moisture content, the onset of transition is influenced by the balance between the fluidity of the matrix and the sorption rate. Therefore, a model strategy that relates the glass transition and moisture sorption kinetics to the humidity-induced-collapse is fundamental for quantitative prediction of the shelf-life of the freeze-dried products, but such a model has not yet been reported. This study is to develop a new mathematical model of sorption kinetics applicable to glassy freeze-dried matrices. By incorporating experimentally obtained moisture sorption isotherms and glass transition lines into the model development, it is shown that the time until the humidity-induced-collapse occurs can be predicted with higher accuracy. Results were visually summarized in stability maps as a function of the storage conditions, such as relative humidity and temperature. The location of the limit line, the border to induce humidity-induced-collapse, was observed to depend on the sorption rate constant, moisture sorption isotherm, and glass transition temperature of the selected material. As expected, matrices (i.e. freeze-dried maltodextrin with different DE values) with relatively high transition temperatures exhibited a wider stability zone. The mathematical model proposed in this study could be a robust tool for quantitatively predicting product stability against storage conditions that reflect the properties of materials.