WATER ACTIVITY VS. EQUILIBRIUM MOISTURE CONTENT
VODENA AKTIVNOST NASUPROT RAVNOTEŽNE VLAŽNOSTI MATERIJALA

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ABSTRACT

Water activity is an important parameter that can be used to predict the stability and safety of food with respect to the most microbiological and biochemical reactions, conditioned by its value. In other words, it describes the degree of the ‘bound’ level of water in the dry material, as well as the indicator of the ability of water to act as a solvent, participant in various biochemical reactions, or growth of different microorganisms. The determination of the minimum value of water activity that allows the growth of certain microorganisms and mechanical and thermal equilibrium of the material with the surroundings, are the most important parameters that characterize the stability of the material. The equilibrium moisture content has fundamental role in food industry and technology from the aspect of design and optimization of drying processes and equipment, design of packing materials for dried products, prediction of quality and stability, as well as for calculation of changes in the moisture content of dried material during its storage. Considering the relationship between these two physical parameters, their interdependence has been shown in this paper.

Key words: water activity, equilibrium moisture content, food materials.

INTRODUCTION

Food materials are multicomponent systems, including water as one of the most important constituents. The state of water in the food system, under different external conditions, temperature and pressure, has crucial role for the protection and preservation of nutritional and organoleptic characteristics of food material.

The concept of water activity has fundamental role in the drying process and food materials stability. The first food stability map based on the concept of water activity, reflects the development of microorganisms and different types of biochemical reactions that occur in the material, such as: oxidation process, browning reactions, enzyme activities and vitamin degradation (Labuza et al., 1972). Later, the upgraded food stability diagram has been proposed (Rahman, 2010). In order to overcome the limitations of the water activity concept, in the scientific literature the glass transition concept has been proposed (Rahman, 2012). On the other hand, the equilibrium moisture content has fundamental role in food industry and technology from the aspect of design and optimization of drying processes and equipment, design of packing materials for dried products, prediction of quality and stability, as well as for calculation of changes in the moisture content of dried material during its storage.

MATERIAL

In this paper, the importance of water activity as one of the most important factors affecting the food quality and stability, as well as the interrelations between two the most important concepts for stability criteria determination: the water activity concept and the glass transition concept, has been highlighted. By analyzing the impact of the water activity value on the achievement of mechanical and thermal material equilibrium, the sorption isotherms as a unique opportunity to experimentally determine the equilibrium moisture content of food materials, have been defined.

DISCUSSION

Water activity and concepts of water activity

Water activity is an important parameter that can be used to predict the stability and safety of food with respect to the most microbiological and biochemical reactions, conditioned by its value. In other words, it describes the degree of the ‘bound’ level of water in the dry material, as well as the indicator of the ability of water to act as a solvent, participant in various biochemical reactions, or growth of different microorganisms.

The determination of the minimum value of water activity that allows the growth of certain microorganisms and mechanical and thermal equilibrium of the material with the surroundings, are the most important parameters that characterize the stability of the material.

Water activity, $a_w$, is defined as a ratio of the partial vapor pressure of water on the material surface, $p_w$, and the partial vapor pressure of pure water, $p_0$, at the same temperature (Rahman, 2009):

$$ a_w = \frac{p_w}{p_0} $$ (1)
The concept of water activity is the most commonly used criterion for determining the stability and quality of food materials in the scientific and engineering literature (Rahman, 2009; Rahman, 2010). It has fundamental role in the drying process and food stability. From a theoretical point of view, this concept is based on the rule of water activity concept that food materials are the most stable at the i.e BET-monolayer moisture content or BET-monolayer water activity, while above or below BET-monolayer they are unstable (Rahman, 2010). The first food stability map (Fig. 1), based on the concept of water activity has been proposed by Labuza, (Labuza et al., 1972; Labuza et al., 1972a; Labuza et al., 1972b).

Later, the upgraded food stability diagram which shows the trend of the microbial growth, biochemical reactions and mechanical properties of the material across three zones of the water activity, has been proposed by Rahman (Rahman, 2009), (Fig. 2). The division of zones of this diagram has been made based on the nature of the connection of water molecules with the dry material. (Rahman, 2010). In spite of the practical usage of the food stability diagram, there are certain limitations (Rahman, 2010). In order to overcome the limitations of the water activity concept, the glass transition concept has been proposed. This concept is based on the mobility of a matrix in the dry material, thus diffusivity of the reactants is very slow through the systems to take part in the reactions and stability has been achieved. According to this concept the state diagram (Fig. 3), which shows two macro regions: above glass line (regions 2, 3, 4) and below glass line (region 1), has been proposed (Rahman, 2010).

In the diagram (Fig. 3) it is shown that food materials are the most stable at and below glass line, while the higher above glass transition line, the higher the deterioration or reaction rates (Rahman, 2010).

Glass transition concept, as a tool for predicting microbiological, physical and chemical changes that occur during processing or storage of food materials, is a subject of interest for many researchers over the years (Roos and Karel, 1991; Slade and Levine, 1994; Champion et al., 2000; Khalloufi and Ratti, 2003; Rahman, 2006; Sablani et al., 2007; Sablani et al., 2009; Djendoubi et al., 2013; Vásquez et al., 2013).

In the course of more precise and unified food stability criteria determination, a combination between the water activity concept and the glass transition concept has been made (Rahman, 2012). Consequently, a state diagram has been designed (Fig. 4).
The present diagram proposed 13 micro regions ranked in accordance with the food material stability. These regions are limited by the glass and BET-monolayer line. With the increase of the number of zones, the food material stability decreases. Thus region-1 is relatively non-reacting and the most stable zone, while region-13 is a highly reacting and the least stable zone (Rahman, 2012).

**Equilibrium moisture content**

Multiplication of the water activity, \( a_w \), by 100 gives the percent equilibrium relative humidity, \( \text{ERH} = u_r \), of the atmosphere in equilibrium with the material

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\text{ERH}(\%) = u_r = 100 \cdot a_w
\]

Equilibrium moisture content of the material, as a state of mechanical and thermal equilibrium, can be achieved with water vapor molecules migration from the moist air to the material – sorption, or migration process in the opposite direction – desorption. Because of the complex structure of food materials, the value of the equilibrium moisture content can’t be calculated in a theoretical way, so it is obtained experimentally by determining the sorption isotherms.

The relationship between equilibrium moisture content of the material and the relative humidity change at constant temperature and pressure of the moist air, yields the moisture sorption isotherm. Sorption isotherms are determined experimentally, or they could be obtained with sorption or desorption process, and the difference between these curves is defined as a hysteresis. Different types of hysteresis, as sorption phenomena have been proposed by Caurie (Caurie, 2007). Depending on their shape, five different types of sorption isotherms I, II, III, IV and V, have been described by Brunauer (Brunauer et al., 1940), (Fig. 5).

![Fig. 5. Classification of the sorption isotherms according Brunauer et al., (1940)](image)

Type I represents the well-known Langmuir isotherm or the similar isotherms which are usually characteristic when the monomolecular moisture layer is present on the inner surfaces of the material. Type II is the sigmoid isotherm obtained in the presence of multilayer moisture on the inner surfaces of the material, as well as presence of soluble substances in the material. Type III, known as the Flory-Higgins isotherm accounts for solvents or plasticizers (such as glycerol) above the temperature of the glass transition. Type IV isotherm shows the adsorption by a hydrophilic solid until a maximum of hydration sites are reached. While type V is the i.e Brunauer-Emmett-Teller (BET) multilayer adsorption isotherm which is characteristic of capillary condensation and largely depends on the size of the pores. The most commonly found isotherms in food products are types II and IV.

Later, Jovanović (Jovanović, 1969) classified the sorption isotherms into eight types. The monomolecular adsorption has been presented by type I, while types II and III have the same shape according to the classification of Brunauer et al., 1940. The similarities with capillary condensation in porous materials are indicated by type IV and V, while in type VI two break points and slow adsorption can be seen until relatively high pressures are achieved. Type VII describes a linear isotherm, while the gradual isotherm is described by type VIII (Fig. 6).

![Fig. 6. Classification of the sorption isotherms according Jovanović, (1969)](image)

There is another classification of sorption isotherms, proposed by Heiss and Eichner (Heiss and Eichner, 1971), according to which type I is characteristic for hygroscopic materials, type II for low hygroscopicity materials, while type III includes a larger number of food materials.

![Fig. 7. Classification of the sorption isotherms according Heiss and Eichner (1971)](image)

**CONCLUSION**

Water activity and the equilibrium moisture content of food materials are two key physical parameters whose values are controlled by the different structural or physical-chemical changes that occur during processing or storage of food materials. Considering the relationship between these two physical parameters, their interdependence has been shown in this paper.

**REFERENCES**


Received: 21.03.2016. Accepted: 07.04.2016.