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Desorption isotherms for fresh beef: An experimental and modeling approach

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ABSTRACT

Desorption isotherms for fresh beef were determined at 30, 40 and 50 °C by the static gravimetric method. The resulting isotherms exhibited a type II sigmoid shape. The BET, GAB and Halsey models were used to fit these experimental data. The GAB model was most accurate for all temperatures and all levels of water activity, followed by the BET and Halsey models. The temperature dependence of GAB constants was estimated. The isosteric heat of desorption and its evolution in relation to moisture content were calculated using Clausius–Clapeyron equations. The monolayer moisture content was determined using the GAB model: it decreased as the temperature increased. The density of bound water, the number of adsorption sites, the sorption surface area and the percentage of bound water were calculated using the Caurie equation: all these quantities decreased as the temperature increased. The Kelvin and Halsey equations were used for calculation of pore size, which increases with an increase in moisture levels and sorption temperature.

1. Introduction

Stability of food products is closely related to their water activity. In general, it is considered that a water activity lower than 0.6 protects products from degradation reactions. Indeed, the growth of microorganisms is inhibited and the enzymes are inactivated. The sorption isotherms are of interest because they provide information on the water activity of a product depending on the environment air temperature and relative humidity.

Sorption isotherms are used a great deal in food sciences and technologies, especially in the drying process, where they are important for determining equilibrium moisture content, the moisture content at the end of the drying process (Talla, Jannot, Nkeng, & Puiggali, 2005). The equilibrium moisture content is an important parameter in models used to predict changes in the moisture content of a product during the drying process and later during storage.

For the drying process control, it is essential to have a good knowledge of the ratio between equilibrium moisture content and the relative humidity of the surrounding environment (Gal, 1983). When the moisture in the product is in equilibrium with the water vapor in the air that surrounds it, the temperature of the product is equal to that of the air and the water vapor pressure in the product is equal to that in the air. The water activity of the product is then equal to the relative humidity of the air. The curve showing the equilibrium moisture content of a product as a function of its water activity for a given temperature is called a sorption isotherm. Desorption isotherms are obtained when a moist product reaches its equilibrium moisture content by giving up water into its surroundings.

Meat preservation in hot countries is difficult because of the very perishable nature of this product. When climate conditions are unfavorable, the product deteriorates very quickly. Since the conditions in tropical countries make use of solar energy for drying food practically attractive, solar drying is widely used as a meat preservation method in tropical countries where there is a variety of dried meat such as *Biltong* in South Africa (Laurent, 1981), *Charque* in Brazil (Shimokomaki, France, & Carvalho, 1987; Torres et al., 1994) and *Kilishi* in the Sahel countries (Kalilou & Zakhia, 1997). The annual consumption of dried meat in developing countries is constantly increasing rising yearly from 10 kg per capita in 1960 to 26 kg per capita in 2000 and will reach 36 kg per capita in 2030 (Heinz & Hautzinger, 2007). Thus, there is need to provide information on sorption isotherms of meat at temperatures encountered in solar drying processes in tropical countries to have a better understanding of the behavior of the product as it dries.

There have been many studies into the sorption isotherms of meat and its by-products (Aktas & Gürses, 2005; Clemente, Bon, Benedito, & Mulet, 2009; Comaposada, Gou, & Pakowski, 2000; Farid & Farid, 2010; Kabil, Aktaş, & Balcı, 2012; Singh, Rao, Anjaneyulu, & Patil, 2001; Trujillo, Pei, & Tuan Pham, 2003) which have mainly covered the effect of temperature on moisture sorption, the study of hysteresis, sorption heat and modeling sorption curves. Some authors have shown that experimental data from sorption isotherms can be used to determine the isosteric sorption heat and the properties of the bound water

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(Delgado & Sun, 2002a; Mulet, Garcia-Reverter, Sanjuan, & Bon, 1999; Singh, Rao, Anjaneyulu, & Patil, 2006). The isosteric heat of desorption is the energy required to remove water molecules from the solid matter of the product. It is equal to the sum of the heat of vaporization of pure water and the net isosteric heat of desorption. This last can be determined by applying the Clausius–Clapeyron equation to desorption isotherms. Knowledge of the isosteric heat of sorption is an important matter for the design of drying equipments. Clemente et al. (2009) and Singh et al. (2006) have studied the isosteric heat of desorption of previously frozen raw pork meat and goat meat, respectively. Kabil et al. (2012) have studied the isosteric heat of desorption of beef for air temperatures below 25 °C, which are temperatures not usually encountered in solar drying processes in tropical countries. It is therefore necessary to provide information on isosteric heat of desorption of beef at solar drying temperatures in order to have a more precise idea of the energy needed for solar drying of beef in tropical countries.

Bound water is often defined as water which is so closely linked to the other constituents of the product that its properties differ from those of the free water. It is a relevant indicator of product stability because it does not allow the development of microorganisms or any chemical reaction (Caurie, 1981). Rizvi (1986) suggested that temperature has an impact on the properties of bound water of food products. Some studies deal with the effect of temperature on the properties of bound water in meat products (Singh et al., 2001, 2006), but none of them looks at beef meat. Therefore, studying the influence of temperature on values of monolayer moisture content, number of sorbed monolayers, density of sorbed water, surface area of sorbent and percent of bound water is useful to assess changes in sorbed water as a function of temperature.

The evaluation of pore size distribution in porous materials is also of great importance in drying practice (Strumillo & Kudra, 1986). Some authors state that the total sorption area, the rate and the extent of hydration of food materials can be determined from the number, size and surface properties of the pores in the protein matrix (Singh et al., 2006). Furthermore, the influence of temperature on pore size has been pointed out (Kapsalis, 1981). Singh et al. (2001, 2006) have studied this influence of temperature on pore size, for smoked chicken sausage and goat meat.

Sorption isotherms of beef meat at temperatures close to those encountered in solar drying processes in tropical countries are rare. Trujillo et al. (2003) studied desorption isotherms of lean beef in the temperature range 5–40 °C but provide no information on the isosteric heat of desorption and the properties of the bound water (which are important for a better understanding of energy supply and stability of the meat product during drying), and did not consider the temperature dependence of the physically significant GAB model parameters.

The aim of this study is to determine and model the desorption isotherms of fresh beef meat. Classical temperatures encountered in solar dryers are explored (30 °C, 40 °C and 50 °C); the isosteric heat of desorption, temperature dependence of bound water, and properties and size of the pores are determined.

2. Material and methods

2.1. Experimental equipment

The equipment used is a temperature-controlled climate chamber (oven) model 53L 220 °C UFB400 (Memmert GmbH, Schwabach, Germany); this is a basic type of universal oven that includes a forced air circulation for a total chamber volume of 53 L. The air temperature range in this oven is from 10 °C above ambient temperature to 220 °C. Air temperature measurement uncertainty is ±0.5 °C. The samples were placed in hermetically sealed jars containing salt solutions. The jars were 11 cm in height and 10 cm in diameter (Fig. 1), in accordance with the Spiess and Wolf (1987) recommendations. The samples were set on a mesh, 10 mm above the surface of the liquid in order to avoid the samples getting wet, as suggested by Trujillo et al. (2003).

2.2. Sample preparation

The beef used was bought from wholesale butchers in the local market in the town of N'Gaoundéré in North Cameroon. Meat comes from freshly slaughtered beef and therefore did not undergo any treatment postmortem. The animal was Goudali Zébus, aged between 4 and 5 years old. The part of the animal that was used was the round of the hind quarters. First the tendons and fat were trimmed from the fresh meat. The meat was then cut along the direction of the fibers into thin strips, 5 cm long, 3 cm wide and 3 mm thick. Fat, protein, moisture and ash were determined using the method of AOAC (AOAC, 1997).

2.3. Determining the equilibrium moisture content of desorption

Desorption isotherms were determined by the gravimetric static method. We used saturated saline solutions covering a relative humidity interval between 5% and 84% (Table 1) (Bizot & Multon, 1978) these solutions were prepared in hermetically sealed jars and kept in the thermostatically controlled chamber. Two samples were suspended in each jar above the saline solutions; thus they remained in an atmosphere with stable temperature and hygrometry. The trials were carried out for three temperature values: 30 °C, 40 °C and 50 °C. To avoid deterioration of the meat, potassium sorbate has been used as a preservative for four solutions whose water activities are greater than or equal to 50% (NaBr, $CuCl_2$, NaCl, and KCl). Thus 25 mg of potassium sorbate was sprinkled on each sample at a ratio of 5 mg for 1 g of the product. This mass is removed from the final equilibrium mass. This preservative has been recommended and used by Singh et al. (2006) in the proportions indicated above and is considered having no influence on the sorption isotherms.

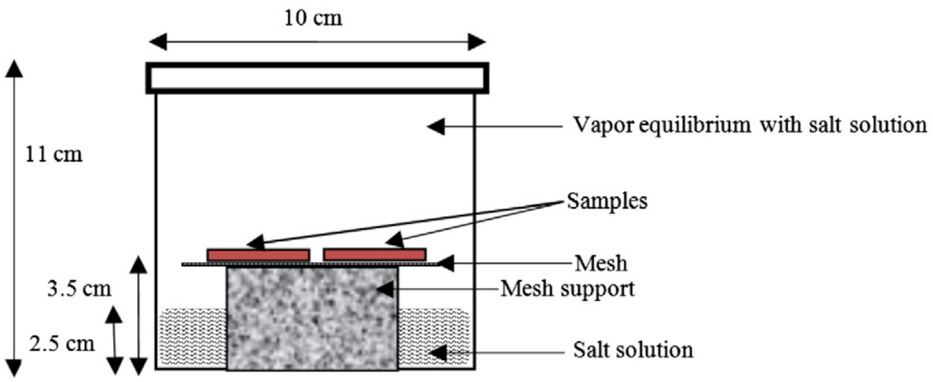

Fig. 1. Schematic diagram of sorption jar and sample holder used in experiments.