

Calorimetric Study of the System Clorhydrate of Chitosan/ Glutaraldehyde(1,5-pentanedial)

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ABSTRACT: The reaction of glutaraldehyde with primary amino groups of chitosan produces covalent crosslinking in a matricial microsphere formulation. The influence of the crosslinking times on the calorimetric parameters (glass transition temperatures, enthalpy, and endothermic peak) of the system clorhydrate of chitosan/glutaraldehyde (1,5-pentanedial) was studied using differential scanning calorime-

try in dynamic mode. Using Kissinger's method, the activation energies for the water remaining process were obtained without a precise knowledge of the reaction mechanism from the experimental endothermic peaks. © 2006 Wiley Periodicals, Inc. *J Appl Polym Sci* 100: 3297–3301, 2006

Key words: calorimetry; chitosan; glass transition; enthalpy

INTRODUCTION

Chitosan is a biodegradable copolymer composed of two subunits, D-glucosamine and N-acetyl-D-glucosamine linked together by $\beta(1,4)$ -glycosidic bonds, derived from the natural polymer chitin, a biopolymer widely distributed in nature.^{1,2}

From a biomedical and technological point of view, it is important that chitosan be nontoxic, biocompatible, biodegradable, acid-soluble, mucoadhesive, and positively charged.^{1,2} On account of these favorable properties, chitosan and chitosan derivatives have been used as flocculants in the treatment of residual waters, in cosmetics, in food industry, and mainly in pharmaceutical industry as drug delivery system.^{3,4}

Chitosan has been reported to be a very useful pharmaceutical material because of its good biocompatibility and low toxicity. General lysozymes degrade chitosan into the body of to N-acetyl-D-glucosamine, which is incorporated in to the glycoproteins pathway.⁵

Glutaraldehyde (1,5-pentanedial) is structurally a linear five-carbon dialdehyde. Its terminal aldehyde groups are chemically reactive, undergoing the typical reactions of aldehyde chemistry as the reactions with amino groups. Entrapment of bioactive molecules in

chitosan microspheres or crosslinked with glutaraldehyde has been successfully studied with diverse applications: waste treatment industry, paper-making, slurry preservations, metalworking fluids, agriculture, animal housing sanitizers, and specially with pharmaceutical purposes.^{6,7}

The main objective of this work was to investigate the reaction of glutaraldehyde with primary amino groups of chitosan to produce covalent crosslinking in a matricial microsphere formulation. In these studies, differential scanning calorimetry was used in dynamic mode to calculate the influence of the crosslinking times on the glass transition temperatures, enthalpy, and endothermic peak. Kissinger's method⁸ has been used to determine the activation energies of this microparticulate system.

EXPERIMENTAL

Microspheres preparation

Plain microspheres were prepared by spraying-drying 1% (w/w) chitosan (Seacure Cl-210, low viscosity grade, and a degree of deacetylation of 83%, Pronova Biopolymers) homogeneous dispersions. Then, 2.52 g of glutaraldehyde (Panreac, Spain) was added to aliquots of 20 g of polymer dispersion.⁹ After incubation for 3, 6, 9, 12, and 18 min, the mixtures were spray-dried (B-191 mini spray drier, Büchi Switzerland) at a feed rate of 2 mL/min, at inlet and outlet drying air temperatures of 110, and 70°C, respectively, and at

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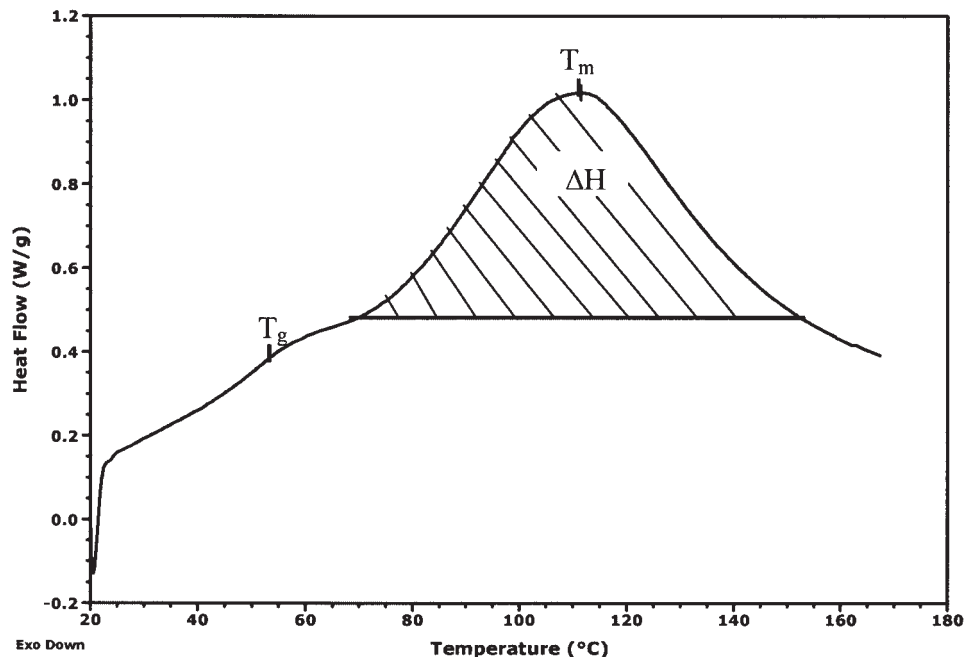


Figure 1 DSC scan at heating rate of 10°C/min.

pressurized air flow of 500 L/h. The obtained microparticles were collected and stored at 50°C until constant weight was reached.

Differential scanning calorimetry

A differential scanning calorimeter Q100 of TA Instruments was used to obtain different calorimetric parameters.

The calorimeter requires three calibrations: T_{zero} calibration, cell constant calibration, and temperature calibration. The T_{zero} calibration requires two experiments: the first one is done without samples; the second one is performed with sapphire disks (without pans) on both the sample and the reference position. The same method was used in both the experiments. It was started with equilibration at an initial temperature, holding isothermally for 5 min, heating at constant rate to a final temperature and holding again isothermally for 5 min. The range of temperatures necessary for this calibration is between -90 and 400°C.

The calibration of enthalpy constant is based on a run in which a standard metal (indium) is heated through its melting transition. The calculated heat of fusion (27.66 J/g) is compared with the theoretical value (28.39 J/g). The cell constant is the ratio between these two values.¹⁰

Temperature calibration is based on a run in which a temperature standard (indium) is heated through its melting transition. The recorded melting point of this standard (157.95°C) is compared with the known

melting point (156.61°C), and their difference is calculated for temperature calibration. The same file used for the cell constant calibration can be used for this calibration.¹⁰

All the experiments were carried out under a nitrogen dry atmosphere at about 5°C to avoid any interferences in the sample (chemical aging). The experiments were carried out in a temperature range from 20 to 180°C.

Mathematical model

Kissinger's method⁸ has been used¹¹⁻¹⁴ to determine the activation energy, E , of the solid state reactions, without a precise knowledge of the reaction mechanism, using the following equation:

$$\ln \frac{\beta}{T_m^2} = \left\{ \ln \frac{AR}{E} + \ln [n(1 - \alpha_{\max})^{n-1}] \right\} - \frac{E}{RT_m} \quad (1)$$

TABLE I
Calorimetric Parameters and Their Standard Errors
Corresponding to Different Crosslinking Time

Reticulation time (min)	T_g (°C)	ΔH (J/g)	T_m (°C)
3	49.54 ± 1.06	88.83 ± 2.78	113.35 ± 2.4
6	51.09 ± 2.42	101.55 ± 1.71	121.69 ± 0.45
9	52.74 ± 4.64	107.01 ± 3.92	128.89 ± 1.18
12	54.19 ± 1.22	119.01 ± 2.44	132.44 ± 0.44
18	55.07 ± 2.15	139.16 ± 2.20	135.74 ± 1.46

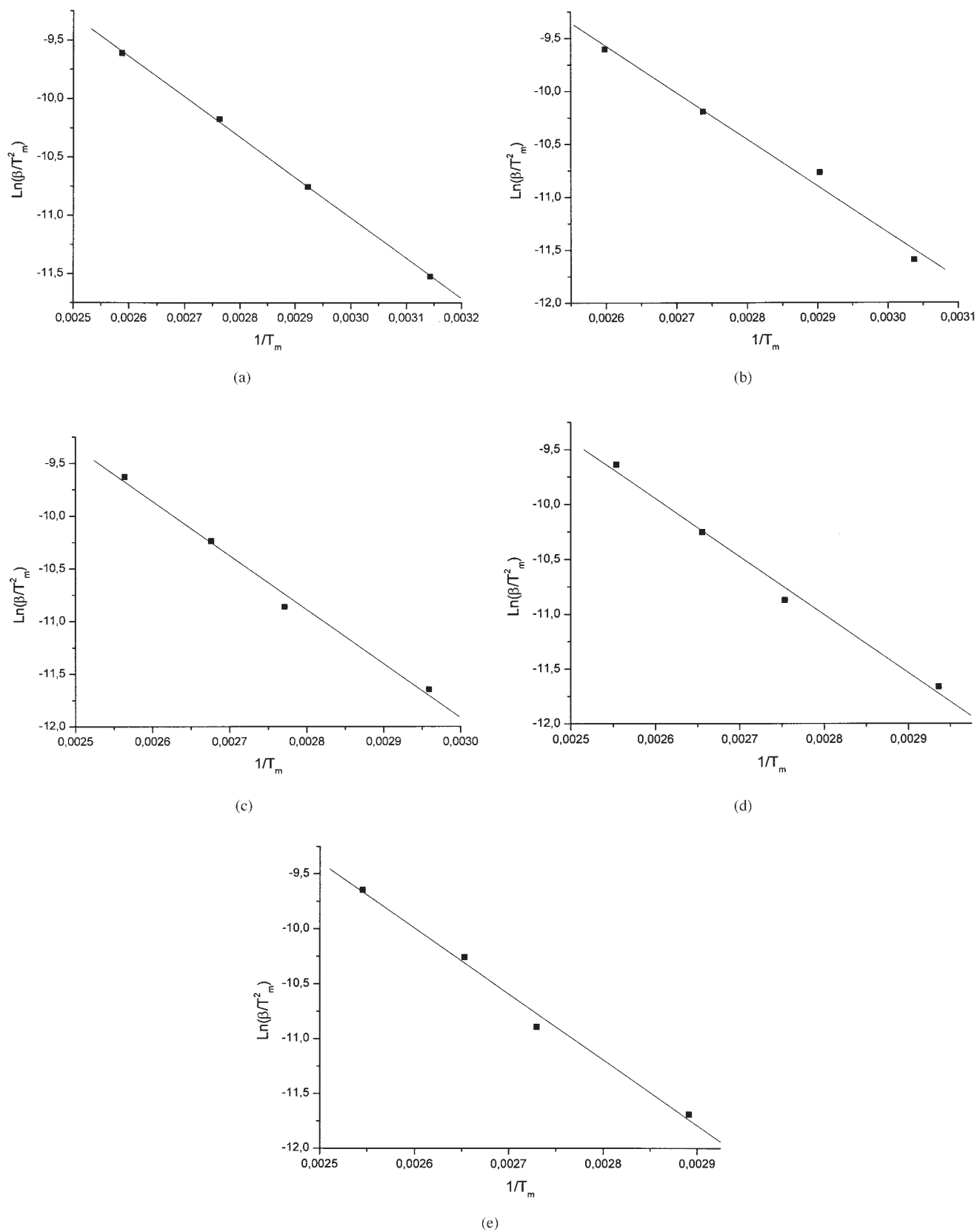


Figure 2 Typical plot of $\ln(\beta/T_m^2)$ vs. $1/T_m$ for the crosslinking time equal to (a) 3 min, (b) 6 min, (c) 9 min, (d) 12 min, and (e) 18 min.

where β is the heating rate, T_m is the temperature corresponding to the maximum point of the calorimetric curves, A is the pre-exponential factor, α_{\max} is the maximum conversion, and n is the reaction order.

RESULTS AND DISCUSSION

Figure 1 shows a characteristic curve to a dynamic calorimetric analysis. From this figure the following parameters were calculated: glass transition temperature (T_g), enthalpy (ΔH), and the endothermic peak (T_m). Glass transition temperature is taken as the inflection point of this transition, enthalpy as the area under the calorimetric curve, and the endothermic peak as the maximum of these curve.

The calorimetric measurements (T_g , ΔH , and T_m) were performed in triplicate for the following crosslinking times: 3, 6, 9, 12, and 18 min. Table I shows the average values and the standard errors corresponding to different crosslinking times. T_g values are practically constants for every experimental crosslinking time periods. These results indicated that crosslinking point already took place before 3 min of experiment. The obtained values are lower than the thermosets,⁹⁻²³ and so it would be necessary to provide a small quantity of energy to achieve the desired elasticity.

Microsphere samples were stored at 50°C until constant weights were reached. Therefore, the enthalpy of the endothermic peak corresponds to phase transition of the water remaining inside microspheres after the aforementioned 50°C treatment. Because of the highly polar nature of this polymer, water can exist as bound water, characterized by strong interactions with the polymer, and as free water present in capillaries and microvoids. Table I shows that the enthalpy increases with the crosslinking time in such a way that higher the crosslinking times, higher is the amount of water kept in the system.²⁴ This trend is observed for the endothermic peak (T_m) as well in the same manner.

We considered the peaks obtained at different heating rates as necessary parameters to determine the activation energy. Using Kissinger's method [eq. (1)] and the experimental data recorded in the DSC curves at different heating rates (1, 2.5, 5, and 10°C/min), the activation energies at different crosslinking times were calculated from straight lines fit of the plots of $\ln(\beta/T_m^2)$ versus $1/T_m$ (Fig. 2). The values obtained for the activation energies at different crosslinking times are shown in Table II. The activation energies increased with the crosslinking times. These values obtained for a natural polymer are lower than those obtained for thermosets,^{9,23} showing that they are more favorable from an energetic point of view.

TABLE II
Activation Energies at Different Crosslinking Times

T (min)	E (kJ/mol)
3	28.76
6	36.57
9	42.66
12	43.99
18	49.86

CONCLUSIONS

The network process of the material is very fast, since after first 3 min the glass transition temperature is practically constant.

The endothermic peaks showed in the experimental plots are due to the water remaining in the microspheres during the crosslinking process, which increases as the crosslinking time is increased. The presence of water in a polymer can lead to marked changes in the chemical structure, in its life time, and originated plasticization effect that produce a decrease in the glass transition temperature. It suggests that water content for a determined storing condition depends on such experimental conditions and on the crosslinking degree, as it can be seen from the high activation energy related to the investigated process. Although the sorption process of liquids takes place through complex mechanisms, water diffusion in polymer with crosslinked structure is frequently represented by Fickian behavior. The amount of substance diffusing throughout in the polymeric material as a function of time is being investigated in current studies.

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