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Determination of polyethylene glycol content in binary polymer blends by size exclusion chromatography with regard to polydispersity

<https://doi.org/10.1515/cdbme-2025-0110>

Abstract:

Using Size exclusion chromatography (SEC), the molar masses M_n and M_w in a binary polymer mixture with polyethylene glycol are to be determined in order to find a mathematical relationship at different PEG contents. Based on this, a quantitative PEG determination in samples with unknown PEG content should then be enabled. It is shown that this mathematical correlation is only found as far as polydispersity is taken into account. The investigations were carried out for two biostable polyurethane-based polymers as well as for three degradable polymers in order to demonstrate the general validity of the results.

Keywords: Polydispersity, molar mass contribution, binary polymer blends, size exclusion chromatography, PEG content.

1 Introduction

The molar mass distribution describes the frequency distribution of individual molecular masses in samples of polymeric substances. Among others, the different mean values M_n (number average molar mass) and M_w (mass average molar mass) are defined to describe the sample statistically [1]:

$$\bar{M}_n = \left(\frac{\sum M_i \cdot n_i}{\sum n_i} \right)$$

$$\bar{M}_w = \left(\frac{\sum M_i \cdot w_i}{\sum w_i} \right)$$

The polydispersity D is a value for the width of a molar mass distribution, it is calculated from the ratio of M_w to M_n :

$$D = \frac{\bar{M}_w}{\bar{M}_n}$$

The shape and width of the molecular weight distribution depend, among others, on the polymerization mechanism and the reaction conditions [2]. Some properties of polymeric materials (e.g. tensile strength and glass transition temperature) are determined by their molecular weight distribution.

Pharmaceutical-grade polyethylene glycol (PEG) is used as an excipient in many pharmaceutical products, in oral, topical, and parenteral dosage forms [3]. It is highly soluble in polar solvents and can therefore be used as an easily extractable component in binary polymer blends with poorly water-soluble polymers to create specific polymer structures such as porosities [4].

2 Materials and methods

2.1 Sample preparation

First, stock solutions with a concentration of 10 g/L each of polyethylene glycol (PEG 3000, Sigma) and the various polymers (Poly-L-Lactide PLLA (Evonik), Poly(L-lactide-co- ϵ -caprolactone) P(LLA-co-CL) (Evonik), Poly(caprolactone) PCL (Perstorp), polycarbonate urethane co-silicone (AdvanSource biomaterials), polyurethane (Lubrizol)) were prepared in chloroform. Binary polymer mixtures were then prepared with a content of 0, 1, 2, 3, 5, 10, 20, 30 and 50 % PEG.

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2.2 Size exclusion chromatography parameter

The mass average molar mass (M_w) and number average molar mass (M_n) of polymer samples at different degradation time points were obtained at 30 °C using a PSS SECcurity SEC system (Polymer Standard Services, Mainz, Germany) including a RI detector combined with a WGE Dr. Bures η 2010 viscosity detector (WGE Dr. Bures, Dallgow, Germany). Separation was carried out with three PSS SDV columns (10^3 , 10^5 and 10^6 Å, respectively). Chloroform stabilized with ethanol was the eluent with a flow rate of 1 ml/min. The samples were prepared with a concentration of 1.5 mg/ml in chloroform with hexylbenzene as internal standard and the injection volume was 0.1 ml. The molecular weights were calculated by the universal calibration method using twelve polystyrene calibration standards in a range between 376 and 2.570.000 g/mol.

3 Results and discussion

The PEG content in the binary polymer blend can change due to the different degradation times of the different polymers and due to the different solubility of the polymers in aqueous systems. However, the different degradation times are not the focus of this study.

A suitable measuring method is required to determine the exact amount of this change in PEG content. The polymers investigated differ in their molecular weight, as a PEG with a low molar mass was chosen because it is readily soluble in water.

The SEC can be used to determine M_n and M_w . Two distinct peaks can be seen in the elugram, as long as the molecular weights of the PEG and the second polymer component are separated by a sufficient value (Figure 1).

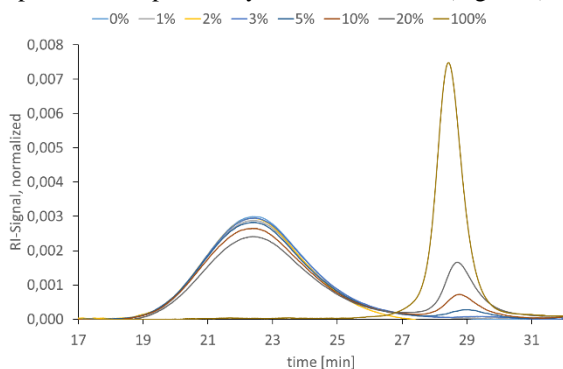


Figure 1: Normalized SEC measurement curves with different PEG contents (RI signals) shown using polycarbonate urethane co-silicone / PEG blends as an example

However, the plot of M_n and M_w as a function of the PEG content does not show a clear and consistent correlation between molar mass and PEG content for different polymers (Figures 2a and 2b).

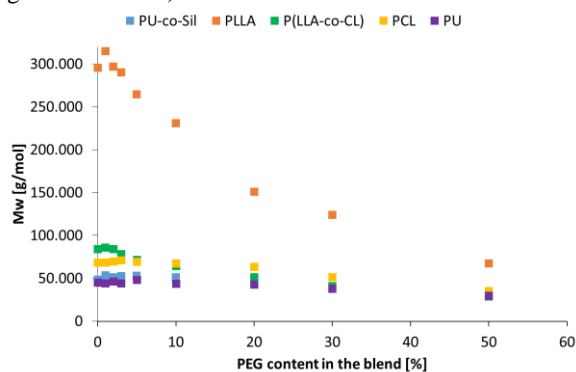


Figure 2a: Dependence of the mass average molar mass of different biostable and degradable polymers on the PEG content.

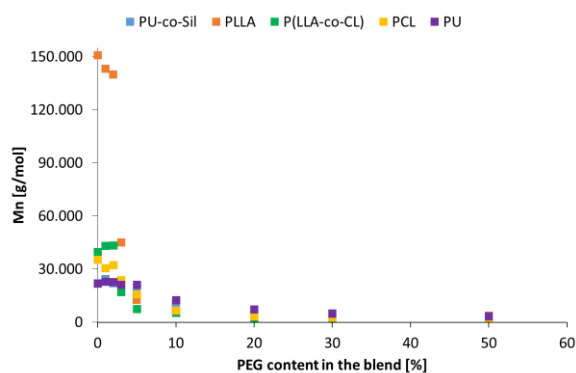


Figure 2b: Dependence of the number average molar mass of different biostable and degradable polymers on the PEG content.

This led to the idea of examining the polydispersity, which is the quotient of M_w and M_n . In general, this value is larger than 1 for pure polymers and is in the low single-digit range. For the polymers used here, the polydispersity is found to be between 1.94 and 2.22.

In the polymeric two-phase system, polydispersities with a value of 5 to 40 can be measured, depending on the type and proportion of the two components. Although there is no linear correlation over the entire range here either (because the low polydispersities of the pure substances are reached at 0 % and 100 %), it can be seen that a linear correlation between polydispersity and PEG content can be observed at least over relevant parts of the diagram (Figures 3a and 3b). This working range is 2% to 5% for P(LLA-co-CL), 2% to 10% for PLLA, 2% to 20% for PCL and polycarbonate urethane co-silicone and even 2% to 30% for Carbothane.

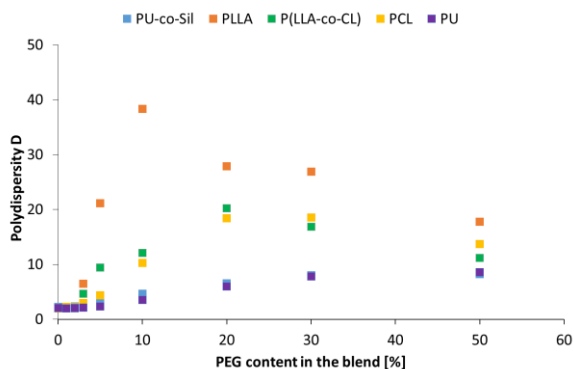


Figure 3a: Dependence of the polydispersity of different biostable and degradable polymers on the PEG content.

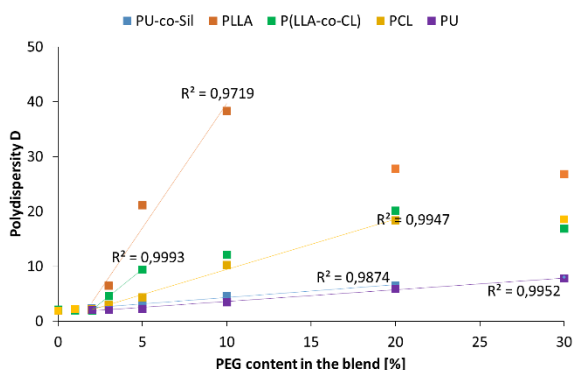


Figure 3b: Dependence of the polydispersity of different biostable and degradable polymers on the PEG content (Detail with linear trendlines and correlation coefficients).

Why are these linear ranges relevant? The PEG used can be washed out of the system due to its good solubility in polar solvents such as water or ethanol. This means that the content after washing declines rapidly into these relevant ranges and can be precisely determined. This can be used to optimize washing processes.

4 Conclusion

A method is presented with which it is possible to determine small amounts of PEG in binary polymer blends. The

investigation included both (two) permanent and (three) degradable polymer partners. The PEG determination is initially based on a measurement of the molar masses using SEC. However, plotting these against the PEG content does not yet allow a clear mathematical correlation.

By determining the polydispersity, however, this correlation emerges and, at least in the relevant range below 5 - 30 % PEG content, a linear range can be clearly recognized, depending on the type of polymer under investigation. This shows a certain general validity of the results.

This enables, for example, washing processes to be optimized to remove the PEG. It is also possible to determine variable polymer contents, e.g. in systems with one or two degradable polymer components.

Author Statement

Research funding: Financial support by the European Regional Development Fund (ERDF) and the European Social Fund (ESF) within the collaborative research between economy and science of the state Mecklenburg-Vorpommern is gratefully acknowledged. Conflict of interest: None. Informed consent: Not applicable. Ethical approval: Not applicable. Acknowledgement: We like to say thanks to Andrea Rohde for the technical support during the experiments.

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