Polymerization of L-Aspartic Acid to Polysuccinimide and Copoly(Succinimide-Aspartate) in Supercritical Carbon Dioxide

Kenneth M. Doll*,1, Randal L. Shogren*,2, Ronald A. Holser1, J.L. Willett2 and Graham Swift3

1Food and Industrial Oil and 2Plant Polymer Research Units, National Center for Agricultural Utilization Research, United States Department of Agriculture, Agricultural Research Service, 1815 N. University St., Peoria, IL 61604, USA, 3Folia Inc., 2800 Milan Court, Birmingham AL 35211

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Abstract: We have prepared two polymeric materials from L-aspartic acid in supercritical carbon dioxide, polysuccinimide and copoly(succinimide-aspartate). The polysuccinimide was characterized by IR spectroscopy and GPC analysis. The copoly(succinimide-aspartate) product was also characterized by titrometric analysis. These natural materials may prove useful in reducing our dependence on petroleum products.

Keywords: Polysuccinimide, copoly(succinimide-aspartate), polyaspartic acid, supercritical carbon dioxide, natural polymer, amino acid polymer.

The synthesis of polysuccinimide from L-aspartic acid, Scheme (1) has a long history [1,2] L-aspartic acid or salts of L-aspartate can be polymerized thermochemically [3-6], with or without acid catalysis [7-11]. It can also be polymerized enzymatically [12]. The physical properties of polysuccinimide have been studied, and found to be favorable for applications as absorbents or viscosity modifiers. Additionally, its amino acid structure makes it inherently more bio-degradable than carbon chain polymers [13]. Even the highly branched form of polysuccinimide formed from maleic acid and ammonia has been shown to be ~70% bio-degradable in wastewater [14].

Polysuccinimide can also be reacted with nucleophiles to form useful derivatives for a variety of applications, such as paper processing, ion exchange, and biomedical release [15]. Recently, a synthesis to yield an alternative form of
polysuccinimide has been developed [6]. This form of polysuccinimide, copoly(succinimide-aspartate; Scheme 2), maintains its water solubility facilitating other developments. Herein we report our patented [16] method for the synthesis of these two polymeric materials in supercritical carbon dioxide solvent. Our synthesis allows these materials to be made in good yield without the use of vacuum system, or toxic organic solvents and catalysts. Furthermore the pressures that are required for the reaction can be achieved by simply heating the reactor.

In order to test whether our synthesis in supercritical carbon dioxide was more general, we performed a polymerization of another natural amino acid, Glutamic Acid. This polymer is often synthesized enzymatically [17], and has found use as a bio-degradable water absorption resin and in drug delivery systems [18]. Using the same conditions as in the polysuccinimide synthesis, we were able to synthesize poly glutamic acid. Both the IR spectra (Fig. (3)) and GPC analysis show that the reaction has occurred forming a polymeric material with a MW between 192 and 900 Daltons.

Finally, we wanted to test our reaction system on a two component system. We synthesized a polymer of the di-acid, adipic acid, with the multifunctional amine, triethylenetetramine (TETA). In this system, the reactants were mixed well, and polymerized using supercritical CO2 as a solvent. As in the other cases, polymerization and could be confirmed by IR spectroscopy (Fig. (4)).

![Fig. 1. The IR spectra of polysuccinimide synthesized in supercritical CO2 at 150 °C (bottom), and 200 °C, (top). Only the higher temperature spectra has a significant imide peak at 1714 cm\(^{-1}\) indicating conversion to product.](image1)

The syntheses were monitored by isolation of the product and study by IR spectroscopy. The main feature in the IR spectra (Fig. (1)) is the imide peak with a frequency of 1714 cm\(^{-1}\). The spectra of the product from the syntheses performed at two different temperatures show that at 150 °C, product is not produced to any significant extent, whereas at 200 °C, the product formation is nearly quantitative. GPC analysis (Fig. (2)) shows a similar trend, where the higher temperature synthesis primarily has material with a MW of >4000, and the lower temperature synthesis shows little molecular weight building.

![Fig. 2. GPC analysis of a hydrolyzed sample of polysuccinimide synthesized in supercritical CO2. The peak at 7.918 min corresponds to a MW of ~4200 daltons when compared to sodium polyacrylate standards. The hydrolysis procedure necessary for solubility of the GPC sample may have reduced the observed MW.](image2)

Our synthesis of polysuccinimide using our CO2 system follows several of the twelve principles of green chemistry [19,20]. The only byproduct formed in our synthesis is water, which possess no toxicity. The rest of the reagent L-aspartic acid, is incorporated into the product yielding an overall 86% atom efficiency. The raw material used is natural and there is no required derivitization or catalyst. Furthermore, the the substances used are not hazardous minimizing the impact of chemical accidents. The

![Fig. 3. The IR spectra of polyglutamate product synthesized in supercritical CO2 at 200 °C (top), and glutamic acid starting material (bottom). The polymerization is shown by the product peak at 1724 cm\(^{-1}\).](image3)

![Fig. 4. The IR spectra of a copolymer of adipic acid and TETA (Triethylenetetramine) product synthesized in supercritical CO2 at 200 °C (top), and the adipic acid starting material (bottom).](image4)

![Fig. 5. The reactor utilized in these syntheses.](image5)
supercritical carbon dioxide serves two purposes. First, it is a good media for dispersing the reactants. Second, it effectively removes the water produced by the condensation reaction allowing the reaction to proceed without the phosphoric acid catalyst often used in other syntheses. It is also important to note that the only high pressure equipment required for our reaction is a reasonably inexpensive pressure reactor (Fig. 5). In conclusion, we have demonstrated a synthesis of the useful products, polysuccinimide and copoly(succinimide-aspartate), and we have also demonstrated the generality of our system as well.

**EXPERIMENTAL**

The reactor employed in this reaction was a 450 mL Parr Series 4560 Bench Top Mini Stirred Reactor, equipped with a standard impeller stirrer (Fig. 5). Teflon or glass reactor liners were used to facilitate reactor cleaning.

First, 1.58 g (0.01 mol) l-aspartic acid (Aldrich, 98+%), was added to the reactor liner which was placed in the reactor and flushed with nitrogen for 1 min, then pressurized with nitrogen to ~0.69 MPa (100 PSI) in order to test for leaks in the system. The nitrogen was vented to ~0.07 MPa (10 PSI). The reactor was pressurized to 5.38 MPa (780 PSI) from a CO$_2$ tank (Air Products) equipped with a syphon tube. The reactor cooling water was started, and the temperature set to 70 °C. The pressure was vented to 7.63 MPa (1106 PSI) at 70 °C, which gives a CO$_2$ density of 0.16 g /mL. The reactor temperature was set to 205 °C, the stirring set to 400 RPM. The reaction was run for 4 hrs. The pressure was slowly vented to 0.07 MPa (10 PSI), the reactor pressurized with nitrogen to 0.80 MPa (116 PSI), and cooled overnight. A solid, light red product was isolated and ground with a mortar and pestle (1.07 g; 78% yield after grinding). Titration by first acidifying with HCl, then titrating with NaOH showed 0.45 equivalents of carboxylate per 100 g of polymer, similar to the expected 0.43 demonstrated for a 1:1 copolymer of succinimide and aspartate.

Poly glutamic acid (Sigma, 99%) and the Adipic acid (Aldrich, 99%), triethylentetraamine (TETA, Aldrich, Tech 60%) copolymer were synthesized by the same method as the polysuccinimide. A slightly larger 600 mL Parr reactor was used without a reactor liner.

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