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Biodegradable Polymers Case Study

Jordi Labs

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CONFIDENTIAL

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Dear Client:

The following test was performed:

1. Standardized Gel Permeation Chromatography (GPC)

Objective

The goal of this study was to demonstrate the importance of GPC in the analysis of commercially available biodegradable materials. Herein, 4 biodegradable polymers, namely polylactic acid (PLA), poly[(R)-3-hydroxybutyric acid] (PHB), polycaprolactone (PCL), and poly(D,L-lactide-*co*-glycolide (PLGA) were analyzed by standardized Gel Permeation Chromatography (GPC), an analytical service offered at Jordi Labs.

Summary of Results

Four (4) biodegradable polymers, PLA, PHB, PCL, and PLGA were analyzed by GPC. The results are summarized in **Tables 1, 2, 3, and 4**.

Background

Biodegradation is the decomposition of chemical materials by environmental factors such as sunlight, temperature changes or microorganisms. Recently, the design and use of biodegradable materials has attracted considerable attention in the polymer and engineering industries, due to their applications in biological/medical systems/devices, and their environmentally friendly aspects compared to traditional plastics.

Biodegradable polymers are desirable for medical applications because they break down or are easily absorbed into the human body and do not need removal or surgical interventions. For this reason, these materials are found in a wide range of medical applications including implantable large devices such as bone plates, small implants such as sutures and drug delivery vehicles, tissue engineering scaffolds, and so on.

Aside from medical applications, biodegradable polymers find application mostly in the packaging industry for the fabrication of disposable materials. According to National Geographic,[1] of the 9.2 billion tons of plastics produced globally between 1950 and 2017, 6.9 billion tons have become waste and only 9% of the latter made it to a recycling bin. This accumulation of degradation resistant plastics has now become a serious global pollution issue. One of the solutions to this issue is the design and use of degradable polymers. Due to their ease of degradation, biodegradable polymers are significantly greener than traditional plastics, and thus have the potential to replace metals and other materials for use as biomaterials in the future.

Gel permeation chromatography (GPC), an analytical technique for the determination of the molecular weight distribution of polymers (Figure 1), can be used to study biodegradable polymers by determining the rate at which a polymeric material might decompose as part of accelerated aging studies. GPC can also demonstrate the absence of degraded polymer chains in a sample. This information can be used for lot release testing for medical devices.

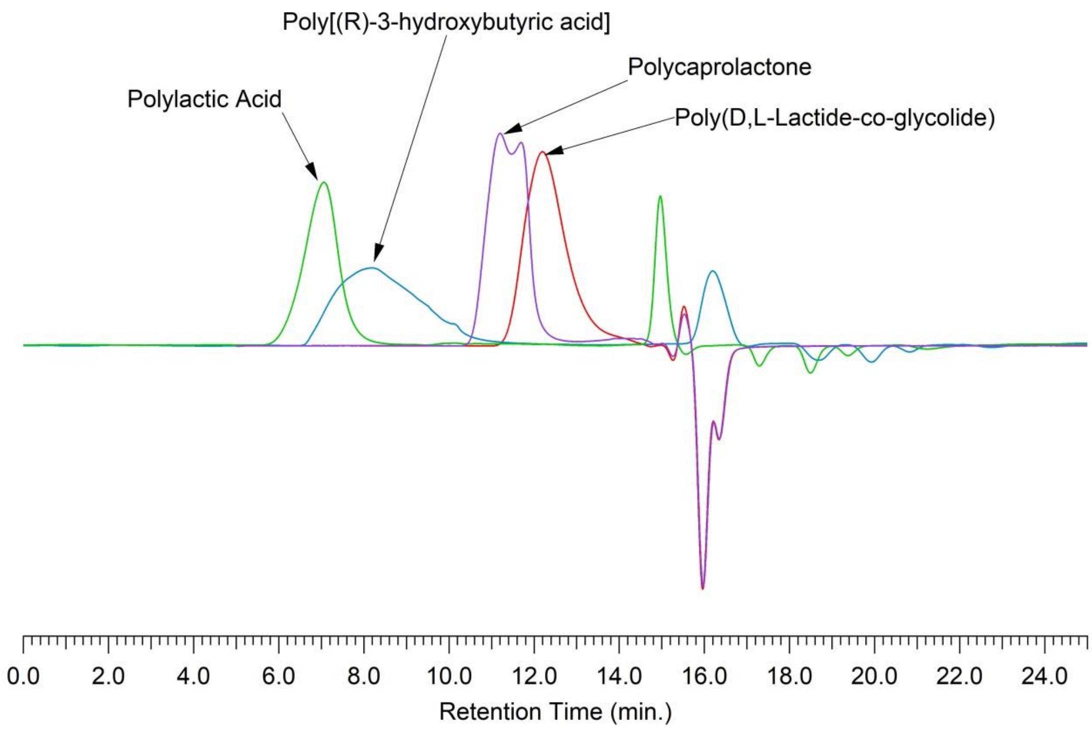

Figure 1. Overlay of biodegradable polymers studied here

1 https://www.nationalgeographic.com/magazine/2018/06/plastic-planet-waste-pollution-trash-crisis/

1. Polylactic Acid

Polylactic acid (PLA), a biodegradable and bioactive polyester that consists of lactic acid building blocks, is derived from renewable resources such as corn starch, cassava, starch, sugarcane, and more.

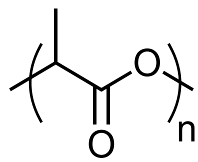

Figure 2. The chemical structure of PLA

Due to its ability to degrade into benign lactic acid which is absorbed inside of the human body, PLA is found in various medical applications as it produces no side effects. PLA breaks down within a relatively short timeframe of 6-24 months under physiological conditions,[2] and is found in several medical implants such as screws, plates, pins, anchors, rods, and more. PLA is also used as a polymeric scaffold for drug delivery purposes.

Under environmental circumstances, PLA can degrade into its natural elements in less than a month, in contrast to other traditional plastics that can take centuries to decompose. As a result, PLA is useful in the production of a range of materials including food packaging bags, disposable tableware, upholstery, disposable garments, diapers, and many more.

Sample Preparation

A PLA sample was dissolved into HFIP with 0.1M NaTFA. The resulting solution was agitated overnight at room temperature, yielding a transparent solution. The sample was then analyzed on a **Jordi Resolve DVB Mixed Bed** column without further preparation.

Results

The calculated molecular weight averages (M_n, M_w, M_z) and dispersity values (PDI) are presented in **Error! Reference source not found.**. The resulting weight fraction below 1 kDa is also presented in **Table 1**. The refractive index chromatogram is presented in **Figures 3**.

Table 1

Actual Mw 60,000 Da

Polymer	M_n (Da)	M_w(Da)	M_z (Da)	PDI	Weight % < 1000 Da
PLA (Relative to PMMA)	50,321	75,300	126,466	1.49	0

[2] Rafael Auras; Loong-Tak Lim; Susan E. M. Selke; Hideto Tsuji (eds.). *Poly(Lactic Acid): Synthesis, Structures, Properties, Processing, and Applications*. doi:10.1002/9780470649848. ISBN 9780470293669.

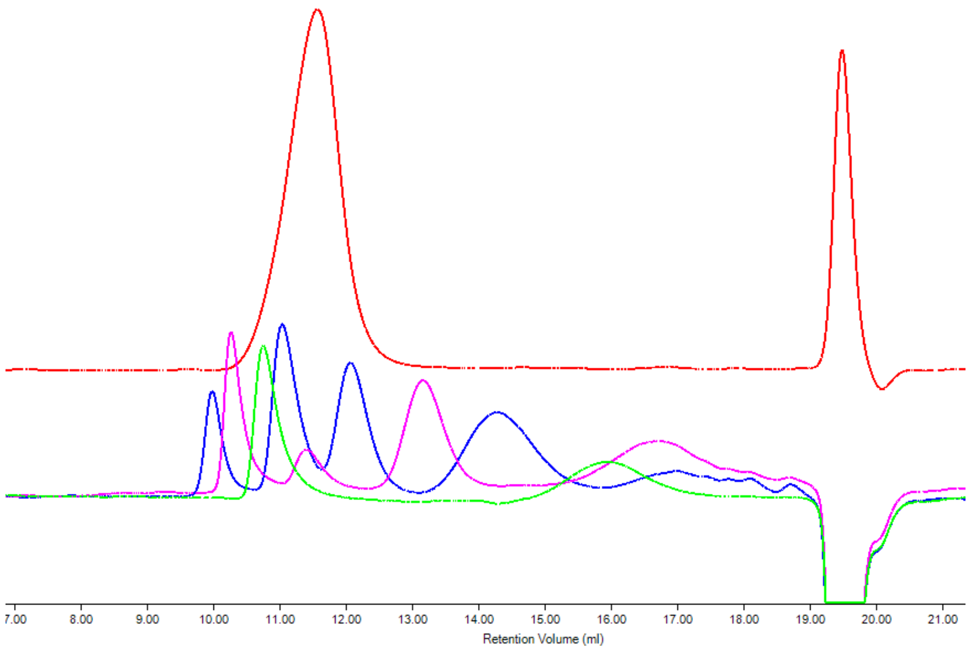

Figure 3. Refractive index (RI) chromatogram of polylactic acid

2. Poly[(R)-3-hydroxybutyric acid]

Poly[(R)-3-hydroxybutyric acid] (PHB) is a biodegradable aliphatic polyester that consists of (R)-3-hydroxybutyric acid building blocks. PHB is readily produced from renewable resources such as sugars, fatty acids and plant oil, microbial processes, and/or the polycondensation of the (R)-3-hydroxybutyric acid monomer.

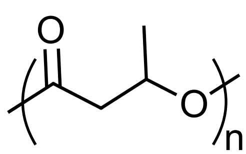

Figure 4. Chemical structure of poly[(R)-3-hydroxybutyric acid]

Among currently available aliphatic polyesters, PHB is more desirable not only because it can undergo biodegradation under various environmental conditions, but also because it possesses properties similar to polypropylene, one of the most widely produced commodity plastics.[3]

[3] Tokiwa, Y., & Ugwu, C. (2007). *Biotechnological production of (R)-3-hydroxybutyric acid monomer. Journal of Biotechnology, 132(3), 264–272*.doi:10.1016/j.jbiotec.2007.03.015

Sample Preparation

A PHB sample was dissolved into HFIP with 0.1M NaTFA. The resulting solution was agitated overnight at room temperature, yielding a transparent solution. The sample was then analyzed using a **Jordi Resolve DVB Mixed Bed** column without further preparation.

Results

The calculated molecular weight averages (M_n, M_w, M_z) and dispersity values (PDI) are presented in **Table 2**. The resulting weight fraction below 1 kDa for is also presented in **Error! Reference source not found.**. The refractive index chromatogram is presented in **Figure 5**.

Table 2

Actual Mw

Polymer	M_n (Da)	M_w(Da)	M_z (Da)	PDI	Weight % < 1000 Da
PHB (Relative to PMMA)	31,928	220,336	1,021,311	6.90	0

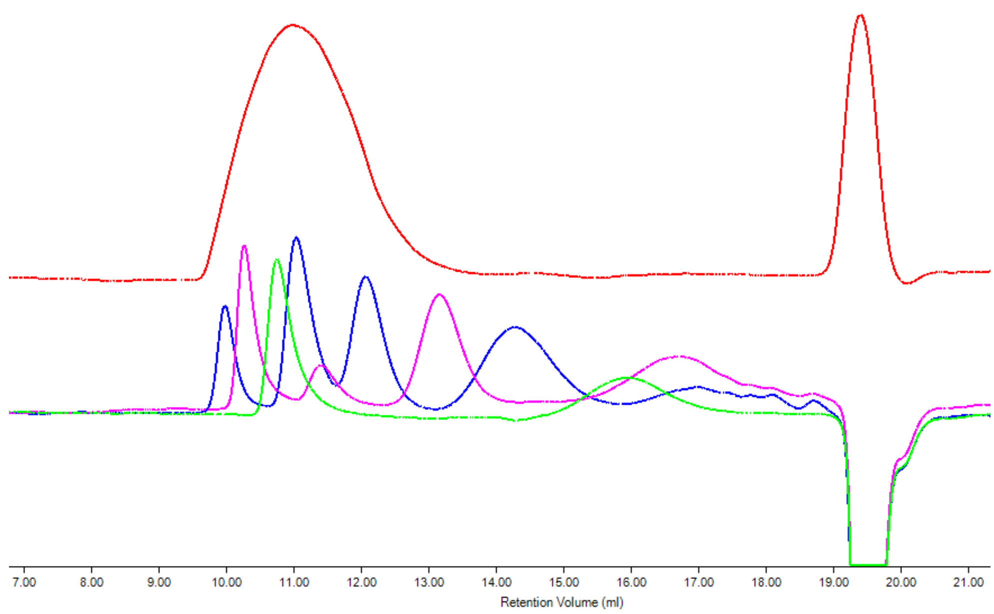

Figure 5. Refractive index (RI) chromatogram of poly[(R)-3-hydroxybutyric acid]

3. Polycaprolactone

Polycaprolactone (PCL) is a biodegradable aliphatic polyester that has a repeat unit of a pentyl group attached to an ester functional group (Figure 6). PCL is commercially prepared by the ring opening polymerization of the cyclic caprolactone monomer in presence of a metal catalyst such as tin(II)octoate.

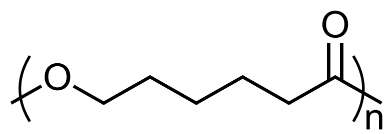

Figure 6. Chemical structure of PCL

Relative to other biodegradable aliphatic polyesters, PCL takes longer to degrade under environmental and physiological conditions due to its reduced ester bond density along the polymer chain.[4] As a result, PCL is more preferable for long-term implantable delivery devices. PCL is widely used in scaffold materials in tissue engineering, and in the delivery of both hydrophobic drugs such as cisplatin, doxycycline, and carboplatin, and hydrophobic drugs such as paclitaxel, ketoprofen, cannabinoid, and many more.[4]

Besides its low degradation rate, PCL is known for its unique property of ductility. When used alone, PCL is a very good elastic biomaterial with a high tensile elongation at break, and can serve as an impact modifier to toughen brittle biodegradable polymers such as PLA via copolymerization or formation of polymer blends.[4]

Sample Preparation

A PCL sample was dissolved into THF overnight. The resulting solution was agitated overnight at room temperature, yielding a transparent solution. The sample was then analyzed using a **Jordi Resolve DVB Mixed Bed** column without further preparation.

Results

The calculated molecular weight averages (M_n, M_w, M_z) and dispersity values (PDI) are presented in **Error! Reference source not found.3**. The resulting weight fractions below 1 kDa for is also presented in **Table 1**. The refractive index chromatogram is presented in **Figures 7**.

[4] Malikmammadov, E., Tanir, T. E., Kiziltay, A., Hasirci, V., & Hasirci, N. (2017). *PCL and PCL-based materials in biomedical applications. Journal of Biomaterials Science, Polymer Edition, 29(7-9), 863–893.*

Table 3

Actual Mn 80,000 Da

Polymer	M_n (Da)	M_w(Da)	M_z (Da)	PDI	IV (dL/g)	Rh (nm)	Weight % < 1000 Da
PCL (Relative to PMMA)	82,736	156,597	274,297	1.83	N/A	N/A	0.918
PCL (Absolute, GPC-T)	82,003	116,678	162,005	1.43	1.00	11.93	0.00

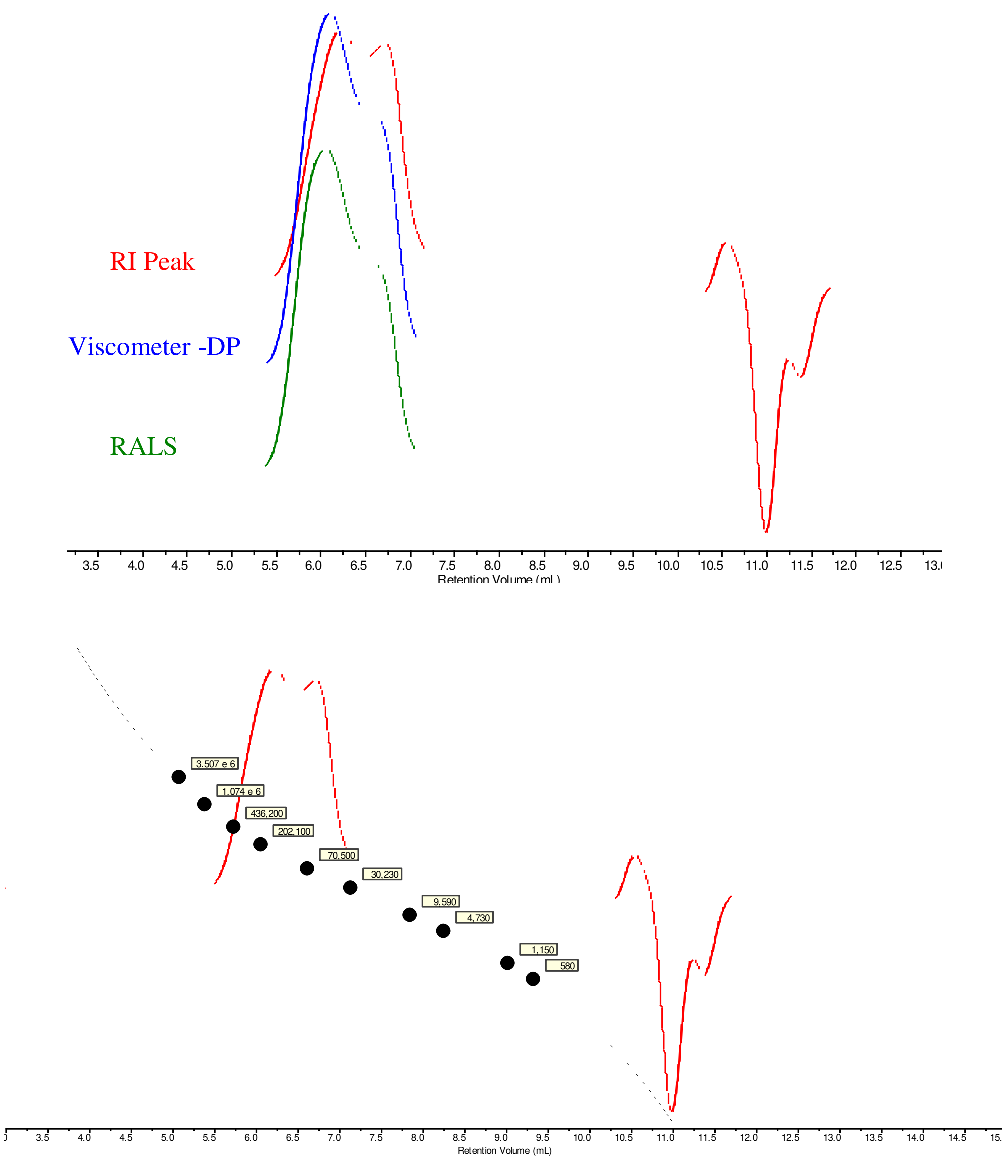

Figure 7. Refractive index (RI) chromatogram of polycaprolactone

4. Poly(D,L-lactide-*co*-glycolide)

Poly(D,L-lactide-*co*-glycolide) (PLGA), a biodegradable and bioactive polyester, consists of alternating lactic acid and glycolic acid building blocks. Low molecular weight PLGA is obtained through a direct condensation polymerization reaction of lactic acid and glycolic acid, while high molecular weight PLGA is produced via the ring opening polymerization of lactide and glycolide, the cyclic dimers of lactic acid and glycolic acid.

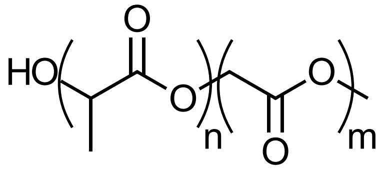

Figure 8. Chemical structure of PLGA

Similarly to PLA, PLGA is unstable under physiological conditions and degrades into non-toxic products including lactic acid, glycolic acid, carbon dioxide, and water. PLGA is, therefore, used in several medical applications as its degradation products are found in various metabolic pathways of the human body and can be safely reabsorbed and processed. Specifically, PLGA is used in the fabrication of medical devices such as grafts, sutures, surgical sealant films, implants, prosthetic devices, and many more.[5]

Sample Preparation

A PLGA sample was dissolved into THF overnight. The resulting solution was agitated overnight at room temperature, yielding a transparent solution. The sample was then analyzed using a **Jordi Resolve DVB Mixed Bed** column without further preparation.

Results

The calculated molecular weight averages (M_n, M_w, M_z) and dispersity values (PDI) are presented in **Table 4**. The resulting weight fraction below 1 kDa is also presented in **Error! Reference source not found.4**. The refractive index chromatogram is presented in **Figures 9**.

Table 4

Actual Mw Unknown

Polymer	M_n (Da)	M_w (Da)	M_z (Da)	PDI	IV (dL/g)	Rh (nm)	Weight % < 1000 Da
PLGA (Relative to PMMA)	11,569	28,171	44,182	2.44	N/A	N/A	1.015
PLGA (Absolute, GPC-T)	11,483	24,610	38,880	2.14	0.216	4.18	0.515

[5] Y.H. Hsu, D.W.C. Chen, C.D. Tai, S.J. Liu*, E.C. Chan, ***International Journal of Nanomedicine***, 9, 4347-4355 (2014)

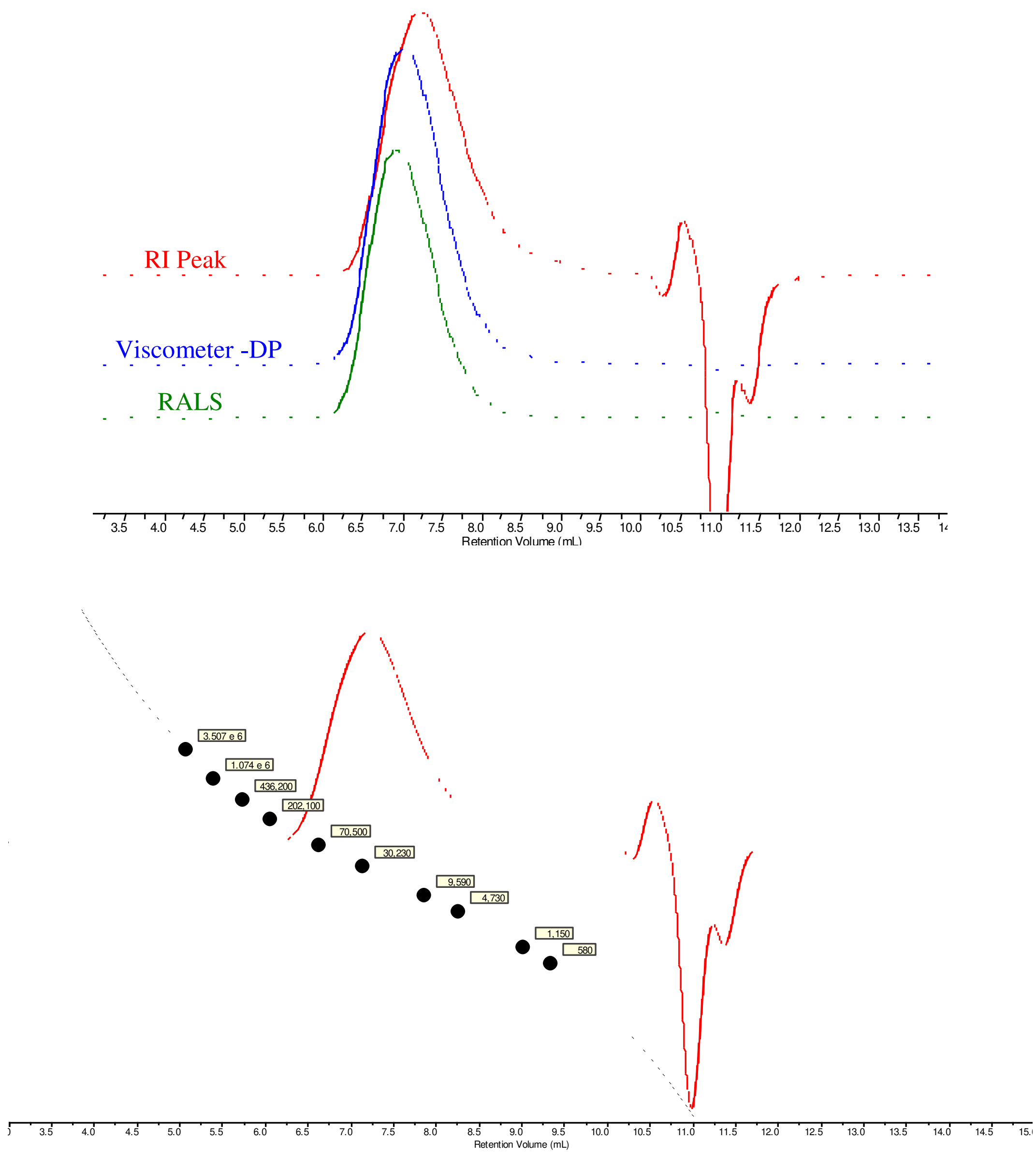

Figure 9. Refractive index (RI) chromatogram of PLGA

Closing Comments

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Jordi Labs specializes in polymer testing and has 30 years experience doing complete polymer deformulations. We are one of the few labs in the country specialized in this type of testing. We will work closely with you to help explain your test results and solve your problem. We appreciate your business and are looking forward to speaking with you concerning these results.

Sincerely,

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