target value of between 0.1 and 0.4 g/mL. Radial compression operations do not change the bed depth of the fiber media packing.

EXAMPLES

Example 1. Melt compounding with mineral or polymeric porogens. In this experiment, nylon was blended with a variety of mineral or polymeric porogen additives such as calcium carbonate, silica, or poly(lactic acid) polymer (PLA). Ternary mixtures of nylon, mineral and PLA polymer porogens were also prepared. These blends were subsequently used for fiber extrusion experiments.

Several blends of nylon 6 and mineral fillers were made using a compounding extruder. Additional blends were also prepared containing a ternary mixture of nylon, PLA and mineral porogens. Four different types of mineral fillers were examined: Albafil A-O-255-12 from SMI, Vicality Heavy from SMI, Multifex-MM™ from SMI, and Syloid 244FP from W.R. Grace. The pre-dried materials were weighed and dry blended. The dry blend was put onto the feed conveyor which was adjusted to sufficiently feed the microtruder. The material was extruded out of a single strand die into a water bath and then pelletized. Certain nylon/porogen formulations employed in this work are summarized in Table ~~2~~ 1 below.

Table 1. Summary of nylon formulations compounded with various mineral and polymeric porogens.

Materials	Blend Ratio	Porogen Type
PA6: Albafil	75:25	Mineral ($CaCO_3$)
PA6:Vicality	75:25	Mineral ($CaCO_3$)
PA6:Syloid	75:25	Mineral (SiO_2)
PA6: Multifex-MM™	75:25	Mineral ($CaCO_3$)
PA6:PLA	75:25	Polymer (PLA)
PA6:PLA:Albafil	65:25:10	Mineral ($CaCO_3$) + Polymer (PLA)
PA6:PLA:Vicality	65:25:10	Mineral ($CaCO_3$) + Polymer (PLA)

PA6:PLA:Syloid	73.1 : 24.4 : 2.5	Mineral (SiO_2) + Polymer (PLA)

Example 2. Melt extrusion of mineral porogen loaded monofilaments. In this experiment, a general description of the process for melt-spinning the blended nylon/mineral porogen pellets into monofilament fibers of approximately 20 micron diameters is provided.

The blended nylon/mineral porogen pellets were melt spun into monofilaments using a fiber spinning machine. The fiber spinning machine is an LBS System from Hills Inc. (Melbourne, FL). The extruded monofilament fiber samples were drawn to a diameter of approximately 20 microns. After fiber spinning, drawing and winding, the mineral porogen was subsequently extracted from the monofilaments according to the procedure described below.

Example 3. Mineral porogen extraction from extruded monofilaments. In this experiment, the process for mineral porogen extraction from extruded monofilament fibers using a 1 M hydrochloric acid solution is described. The fibers are subsequently neutralized, washed, and the surfaces of the fibers are inspected by scanning electron microscopy (SEM). Kr BET surface area measurements are also conducted.

Into a 100 mL glass jar with cap were added 1.0 g of extruded monofilament (approximately 20 µm diameter) and 50 mL of 1.0 M HCl (50 mmol). The suspension was agitated at 30 °C overnight. The fiber solids were isolated by vacuum filtration and washed with 0.5 M Tris-HCl (1 x 100 mL), DI water (1 x 100 mL) and ethanol (1 x 100 mL). The material was placed in an oven to dry at 40 °C for 18 hours. The results of the mineral porogen extraction experiments are shown in Table ~~3~~ 2 below. SEM inspection of the fiber surface morphology was conducted after extraction of the mineral porogens and these images are shown in the FIG. 2. The

Albafil®-containing monofilament affords large micron-sized pores or cavities on the fiber surfaces after porogen extraction. Due to the smaller particle size of the Multifex-MM™-porogen (< 0.2 microns), much smaller pores are observed on the fiber surface after porogen extraction. No such pores are evident on a similarly-treated nylon fiber control sample. Kr BET surface area measurements reveal a significant gain (~300%) in BET surface area for the material prepared using the Albafil® porogen over the non-porous nylon fiber control sample.

Table 2. Calcium carbonate mineral porogen extraction.

Sample ID	Fiber amt (g)	monofilament blend composition (nylon:mineral)	Obtained	% yield (expected yield)	Kr BET Surface area
7746-34A	0.46 g	PA6 (100:0)	0.44 g	96% (100%)	0.12 m^2/g
7746-34B	0.92 g	PA6:Multifex-MM™ $CaCO_3$ 75:25	0.68 g	74% (75%)	--
7746-34C	0.61 g	PA6:Albafil $CaCO_3$ 75:25	0.47 g	77% (75%)	0.33 m^2/g

Example 4. Melt compounding with polymeric porogens. In this experiment, nylon was blended with various amounts of a polymeric porogen, poly(lactic acid) polymer. These blends were subsequently used for fiber extrusion experiments.

A variety of nylon/PLA blend samples were generated using a compounding extruder. A range of PLA and Nylon 6 blends were made and are shown in Table ~~4~~ 3 below. The appropriate amount of dried pellets were weighed and dry blended. The dry blended mixture was then added to the feed conveyor belt on the compounding extruder. The feed belt was adjusted to sufficiently feed the compounding extruder. The material was extruded out of a single strand die into a water bath and then pelletized.

Table 3. Summary of nylon formulations compounded with PLA as a polymeric porogen.

Materials	Blend Ratio
PA6:PLA	80:20
PA6:PLA	75:25
PA6:PLA	70:30
PA6:PLA	65:35
PA6:PLA	60:40
PA6:PLA	55:45
PA6:PLA	50:50

Example 5. PLA porogen extraction from extruded filaments. In this experiment, the process for PLA porogen extraction from extruded filaments from the melt compounder using a 1.5 N sodium hydroxide solution is described. The fibers are subsequently neutralized, washed, a gravimetric assay is performed, and the surfaces of the fibers are inspected by scanning electron microscopy (SEM).

Into a 250 mL glass jar with cap were added 2.0 g of extruded filament (approximately 2.0 mm diameter) and 0.2 L of 1.5 N NaOH (0.75 mol). The suspension was stirred at room temperature overnight. The fiber solids were isolated by vacuum filtration and washed with DI water (3 x 250 mL) and ethanol (1 x 250 mL). The material was placed in an oven to dry at 60 °C for 3 hours. The results of the PLA polymeric porogen extraction experiments from the extruded 2 mm filaments are shown in Table ~~5~~ 4 below. From these data, it can be seen that the PLA porogen is more easily extracted for the high PLA loading sample (50 wt% PLA) than it is for the low PLA loading sample (35 wt% PLA). The large difference between the actual and expected yields is due to restricted access to the interior of these large 2 mm diameter filaments. SEM inspection of the filament surface morphology was conducted after extraction of the PLA polymeric porogen and these images are shown in FIG. 3. These data show the appearance of a fibrillated surface

morphology after PLA porogen extraction from the filaments. These surface features are quite pronounced for PLA loadings equal to or greater than 40 wt%. Fibrillated surface morphologies such as these are expected to greatly increase the surface area of a fiber substrate.

Table 4. PLA porogen extraction from extruded filaments.

Sample ID	Fiber amt (g)	filament blend composition (nylon:PLA)	Obtained	% yield (expected yield)
7895-126A	1.94 g	65:35	1.94 g	100% (65%)
7895-126B	1.99 g	60:40	1.80 g	90% (60%)
7895-126C	1.84 g	55:45	1.60 g	87% (55%)
7895-126D	1.82 g	50:50	1.59 g	85% (50%)

Example 6. Melt extrusion of polymeric porogen loaded fibers. In this experiment, a general description of the process for melt-spinning the compounded nylon/PLA polymer porogen pellets into core/sheath or 15 wing bi-component fibers of approximately 20 micron diameters is provided.

The blended nylon/PLA pellets were melt spun into fibers using a bi-component fiber spinning machine. The bi-component fiber spinning machine is an LBS System from Hills Inc. (Melbourne, FL). The extruded fiber samples were core/sheath and 15 wing fibers with a sheath of PLA and the blended pellets in the core (or vice versa). Samples are summarized in Table ~~6~~ 5 below.

Table 5. Summary table of extruded fibers containing polymeric porogens located within the fiber core or as a porogen-loaded external sheathing.

Sample ID	Fiber type	Core blend composition (nylon:PLA)	Sheath composition	Core/Sheath ratio

7895-122 core 2	Core/Sheath	80:20	PLA	50:50
7895-122 core 4	Core/Sheath	75:25	PLA	50:50
7895-128 core 4	Core/Sheath	65:35	PLA	50:50
7895-128 core 6	Core/Sheath	60:40	PLA	50:50
7895-128 core 7	Core/Sheath	55:45	PLA	50:50
7895-128 core 8	Core/Sheath	50:50	PLA	50:50
7895-123 core 6	15 wing	70:30	PLA	1:2
7895-159 core 2	Core/Sheath	100:0	nylon:PLA 60:40	50:50
7895-159 core 4	Core/Sheath	100:0	nylon:PLA 60:40	2.6:1
7895-159 core 1	Core/Sheath	100:0	nylon:PLA 60:40	8:1
7895-159 core 5	Core/Sheath	100:0	nylon:PLA 60:40	1:2

Example 7. Melt extrusion using hand-blended samples. In this experiment, a general description of the process for melt-spinning a hand-blended mixture of nylon and PLA polymer porogen pellets into core/sheath bi-component fibers of approximately 20 micron diameters is provided.

A variety of melt-extruded fiber samples were generated by melt spinning using a lab scale bi-component extruder from Hills Inc. (Melbourne, FL) mounted with a core/sheath spin pack. The sheath side of the die was fed with polylactic acid (PLA) pellets. For the core side of the die, polymer pellets were mixed at various ratios by simple agitation in a bag before being fed into the extruder. Fibers were drawn and wound on a core for later processing and analysis. Samples are summarized in Table ~~7~~ 6 below.

Table 6. Summary table of extruded fibers containing hand-blended polymeric porogen / nylon mixtures located within the fiber core.

Sample ID	Fiber type	Core hand-blend composition (nylon PA6:PLA)	Sheath composition	Core/Sheath ratio
7993-6A	Core/Sheath	30:70	PLA	50:50

7993-6B	Core/Sheath	35:65	PLA	50:50
7993-6C	Core/Sheath	40:60	PLA	50:50
7993-6D	Core/Sheath	60:40	PLA	50:50
7993-6E	Core/Sheath	65:35	PLA	50:50
7993-6F	Core/Sheath	70:30	PLA	50:50

Example 8. General procedure for PLA extraction. In this experiment, the process for PLA porogen extraction from extruded bicomponent core/sheath fibers using a 1.5 N sodium hydroxide solution is described. The fibers are subsequently neutralized, washed, a gravimetric assay is performed, and the surfaces of the fibers are inspected by scanning electron microscopy (SEM). Kr BET surface area measurements are also conducted.

Into a 1 liter Pyrex bottle with cap were added 5.0 g of cut staple fiber (1.0 mm length) and 0.5 L of 1.5 N NaOH (0.75 mol). The suspension was stirred at room temperature overnight. The fiber solids were isolated by vacuum filtration and washed with DI water (3 x 250 mL) and ethanol (1 x 250 mL). The material was placed in an oven to dry at 60 °C for 18 hours. The results of the PLA polymeric porogen extraction experiments from extruded bi-component fibers (20 micron diameter) are shown in Table ~~8~~ 7 below. From these data, we find that the PLA porogen was extracted from both the fiber sheath and from within the fiber core for all fiber samples. The small difference between the actual and expected yields is evidence of complete extraction of the PLA porogen from within the bi-component fiber. SEM inspection of the fiber surface morphology was conducted after extraction of the PLA polymeric porogen and these images are shown in FIG. 4. From these data, we find the appearance of a fibrillated surface morphology after PLA porogen extraction from the fibers with PLA loadings greater than 35 wt%. These fibers appear to be constructed of bundles of highly entangled nylon nanofibrils. For PLA porogen loadings greater

suspension was sparged with N_2 for 5 minutes, the vial sealed and heated to 80 °C overnight. The suspension was cooled to room temperature. The fiber solids were isolated by vacuum filtration and washed with DI water (5 x 30 mL), and ethanol (1 x 30 mL). The fibers were dried at 60 °C for 2 hours. Results for the surface modification of a surface area enhanced (SAE) core/sheath fiber as well as a non-porous 15 wing control sample are shown in Table ~~9~~ 8 below. Static binding capacity measurements were also conducted for both of these sulfonic acid functionalized fibers using IgG, lysozyme, and methylene blue as large protein, small protein, and small molecule probes, respectively. Standard cation exchange binding conditions were employed for all of these static binding capacity tests and the results are summarized in FIGS. 9, 10, 11 and in Table ~~10~~ 9 below. From these data, an increased static binding capacity for the SAE fiber over the 15 wing fiber is shown, as well as that the binding capacity advantage for the SAE fiber increases with decreasing molecular size.

Table 8. Surface modification of SAE nylon and 15 wing fibers, BET surface area, and recovery data.

Sample ID	Fiber amt (g)	Fiber description	Kr BET Surface area	Obtained	% yield
7895-179A	0.20 g	SAE	10.57 m^2/g	0.19 g	95%
7895-179B	0.20 g	15 wing	1.43 m^2/g	0.17 g	85%

Table 9. Summary of static binding capacity data for SP modified SAE and 15 wing fibers.

	IgG	Lysozyme	Methylene Blue
Molecular weight	160 KDa	14.3 KDa	374 Da
15W fiber SBC (mg/g)	25	21	8
SAE fiber SBC (mg/g)	58	62	38
SAE fiber (SBC gain)	2.3x	2.9x	4.8x
Est. accessible surface area[1]	3.2 m^2/g	4.2 m^2/g	6.7 m^2/g
% of BET surface area	31%	40%	64%

Graft polymerization of HPA/MBAm modified nylon fibers. Into 3 x 125 mL glass jars were added 2-Acrylamido-2-methyl-1-propanesulfonic acid sodium salt (AMPS-Na), water, HPA/MBAm modified SAE nylon fibers (see above) and 1 M HNO3 solution (in the amounts described in the table below). A 0.4 M solution of ammonium cerium(IV) nitrate (CAN) in 1 M HNO3 were added to each bottle. The reaction bottles were capped, sparged with nitrogen, and the mixtures were heated to 35 °C for 18 hours.

After cooling to room temperature, the solids were washed with a solution of 0.2 M ascorbic acid in 0.5 M sulfuric acid (3 x 80 mL), DI water (3 x 80 mL), 0.5 M sodium hydroxide solution (3 x 80 mL), DI water (3 x 80 mL) and ethanol (1 x 80 mL). The material was placed in an oven to dry at 60 °C for 18 hrs.

Obtained samples of a white fibrous solid (see table for recovery and weight add-on data).

Table 10. Cerium redox graft polymerization compositions and recovery data.

Reaction #	HPA/MBAm fiber (g)	AMPS-Na monomer, g (mmol)	CAN (mM)	HNO3 (mM)	water (mL)	Product wt, g (% add-on)
7895-136A	1.5 g	1.37 g (6 mmol)	3 mM	31 mM	44 mL	1.45 g (-3%)
7895-136B	1.5 g	4.11 g (18 mmol)	3 mM	31 mM	42 mL	1.51 g (+1%)
7895-136C	1.5 g	5.46 g (24 mmol)	3 mM	31 mM	40 mL	1.54 g (+3%)

Example 12. Static binding capacity measurement. In this experiment, the IgG static binding capacity of the SP surface-modified SAE fibers in a cation exchange mode is presented.

The results of IgG static binding capacity measurements for the SP-modified SAE nylon fibers are provided in Table ~~12~~ 11 below. From these data, substantial IgG static binding capacities are shown for the SP surface-modified SAE fibers and these IgG SBC

values are comparable to commercial bead-based cation exchange chromatography resins.

Table 11. IgG static binding capacity (SBC) data for SP modified SAE nylon fibers. Challenge: 2 g/L polyclonal human IgG (SeraCare Life Sciences, Milford, MA) in 50 mM Sodium Acetate (pH 5).

Sample	Fiber Amt (mg)	IgG Bound (mg)	SBC (mg/g)	SBC (mg/mL)[1]
7895-136A-1	56	8.0	143	47
7895-136A-2	32	4.6	143	47
7895-136B-1	44	8.1	185	61
7895-136B-2	59	10	177	58
7895-136C-1	62	12	197	65
7895-136C-2	69	4.2	61	20

[1]*Based on a 0.33 g/mL fiber packing density*

Example 13. Dynamic binding capacity measurement. In this experiment, the packing of the SP surface-modified SAE fibers into a chromatography column and permeability of the packed fiber bed is described. The IgG dynamic binding capacity of the SP surface-modified SAE fibers in a cation exchange mode is also presented.

The results of IgG dynamic binding capacity measurements for the SP-functionalized SAE fiber media of example 7895-136B are provided in Table ~~13~~ 12 below. 1.0 g of the media was packed into an 11 mm internal diameter Vantage column and compressed to a bed depth of 3.0 cm (2.85 mL column volume, 0.35 g/mL fiber packing density). The packed fiber permeability at 0.35 g/mL was determined to be 200 mDa using 50 mM acetate buffer (pH 5). The dynamic

before being fed into the extruder. For this example, the blend components were PLA and nylon 6. Fibers were drawn and wound on a core for later processing and analysis. Samples are summarized in the table below. After extraction of the PLA polymeric porogen from within the 'sea' domain of the extruded bi-component fiber, a CIST fiber having a porous structure is provided. Several examples of CIST type fibers are summarized in Table ~~15~~14, below. The general procedure for the extraction of the PLA polymeric porogen is described in the example above. Various CIST fiber samples prepared using a range of nylon/PLA porogen blends as the fiber 'sea' domain composition were prepared. Surface and cryo-SEM cross section images of a CIST fiber and a SAE type fiber are provided in FIG. 12. From the cross section images, it can be seen that large channels or crevices extending throughout the interior of the CIST fiber and these features may make the internal surface considerably more accessible than for the SAE-type fiber. Such features are expected to improve the access of large proteins and biomolecules to the interior surface area of such nano-fibrillated fiber supports.

Table 13. Summary table of extruded 'connected islands in the sea' (CIST) fibers containing 36 nylon PA6 'islands' and hand-blended polymeric porogen / nylon mixtures as the fiber 'sea' component.

Sample ID	Fiber Type	Island Composition	Sea blend composition (nylon:PLA)	Island/Sea ratio
7895-188D	CIST	PA6	PA6:PLA 40:60	1:1
7895-188A	CIST	PA6	PA6:PLA 60:40	3:2
7895-189D	CIST	PA6	PA6:PLA 40:60	1:1
7895-189A	CIST	PA6	PA6:PLA 60:40	1:1
7993-8A	CIST	PA6	PA6:PLA 55:45	2.1:1
7993-8B	CIST	PA6	PA6:PLA 55:45	1:1
7993-8C	CIST	PA6	PA6:PLA 55:45	0.6:1
7993-8D	CIST	PA6	PA6:PLA 60:40	2.1:1
7993-8E	CIST	PA6	PA6:PLA 60:40	1:1

142A and 7895-142B), we find that an increase in 3-SPMA monomer from 7.5 mmol to 19 mmol in the grafting step affords a substantial increase in IgG static binding capacity from 47 mg/g to 212 mg/g. The CIST fibers (entry 7993-2A-1, 7993-2A-2) give comparable IgG SBC values to the SAE type fibers at the low 3-SPMA monomer loading condition (7.5 mmol). The 15 wing fiber (entry 7895-62D) was modified using 38 mmol of 3-SPMA monomer and this sample affords an IgG SBC value of 130 mg/g. In comparison, simple 15 micron round fibers provide very low IgG SBC values under all of the grafting conditions evaluated. This may be attributed to the very low surface area of round fibers which lack projections or internal porous structures.

The results of IgG static binding capacity measurements for the SP modified surface area enhanced (SAE), 'connected islands in the sea' (CIST), non-porous 15 wing and round control fibers (15 µm diameter) are provided in Table ~~17~~ 16 below.

Table 16. IgG static binding capacity data for SP modified surface area enhanced (SAE), 'connected islands in the sea' (CIST), non-porous 15 wing and round control fibers (15 µm diameter). Challenge: 2 g/L polyclonal human IgG (SeraCare Life Sciences, Milford, MA) in 50 mM Sodium Acetate (pH 5).

Sample	Fiber type	Base fiber surface area (m2/g)	BET Method	Fiber Amt (mg)	IgG Bound (mg)	SBC (mg/g)
7895-142A-1	SAE	10.6	Kr BET, multipoint	53	2.7	50
7895-142A-2	SAE	10.6	Kr BET, multipoint	74	3.3	45
7895-142B-1	SAE	10.6	Kr BET, multipoint	63	11	176
7895-142B-2	SAE	10.6	Kr BET, multipoint	54	13	248
7993-2A-1	CIST	4.4	N2 BET, singlepoint	49	2.7	56