Supporting Information

Continuous synthesis of grafted polyesters through successive photocontrolled BIT-RDRP and ROP strategy in flow tube reactors

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1. Experimental Section

1.1. Materials and Apparatus

2-Hydroxyethyl methacrylate (HEMA, 97%) and 1,3,4,6,7,8-hexahydro-2*H*-pyrimido[1,2-*a*]pyrimidine (TBD, 97%) were purchased from Energy Chemical. δ-valerolactone (VL, 98.5%), ε-caprolactone (CL, 99%,) were purchased from Adamas. 1,1,3,3-Tetramethylurea (TMU, 98%), sodium iodide (NaI, 99%), and benzoic acid (99%) were purchased from TCI. Butyl methacrylate (BMA, 98%), dimethyl sulfoxide (DMSO, 99.7%), 1,3-dimethyl-2-imidazolidinone (DMI, 99%) and tetramethylguanidine (TMG, 99%) were purchased from Aladdin. *N*-methyl-2-pyrrolidone (NMP, 98%) and *N*,*N'*-dimethylformamide (DMF, 98%) were purchased from Shanghai Chemical Reagents Co., Ltd.. 1,4-Dioxane (99%), tetrabutylammonium iodide (TBAI, 98%), 1,3,4,6,7,8-hexahydro-1-methyl-2*H*-pyrimido[1,2-*a*]pyrimidine (MTBD, 97%), and *N*-(4-pyridyl)dimethylamine (DMAP) were purchased from Acmec. Dichloromethane (DCM, analytical reagent) and toluene (analytical reagent) were purchased from Chinasun Specialty Products Co., Ltd.. Ethyl α-bromophenylacetate (EBPA, 97%) were purchased from Alfa Aesar. $_{L}$-Lactide (LA, 99%) and 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU, 98%) were purchased from J&K. Triethylamine (TEA, 99%) were purchased from Macklin. Butyl methacrylate, 2-hydroxyethyl methacrylate were passed through a neutral alumina column to remove inhibitors before use. δ-valerolactone, and ε-caprolactone were dried by CaH_2 under reduced pressure. $_{L}$-Lactide was recrystallized twice from dried ethyl acetate. Other materials were used without further purification unless mentioned. The TD-1 gradient mixer and metering pump (P230 II high-pressure constant flow pump, 0.001-9.999mL/min) was purchased from Dalian Elite Analytical Instrument Co., Ltd.. The thermal Imager (XINTEST HT-18) purchased from Dongguan Xintai Instrument Co. Ltd. was used to monitor the temperature of the reaction

1.2. Synthesis of P(BMA-*co*-HEMA) copolymer via photocontrolled BIT-RDRP in a batch reactor

A typical polymerization protocol for the synthesis of P(BMA-*co*-HEMA) with a molar ratio of $[BMA]_0/[HEMA]_0/[EBPA]_0/[NaI]_0/[TEA]_0$ = 50/50/2/10/2 was as follows. A mixture of BMA (311 μL, 1.94 mmol), HEMA (243 μL, 1.94 mmol), EBPA (14.0 μL, 0.08 mmol), NaI (58.7 mg, 0.39 mmol), TEA (10.9 μL, 0.08 mmol), and DMSO (1.5 mL) was placed into an ampoule equipped with a stir bar. Subsequently, the solution was deoxygenated by six freeze-pump-thaw cycles, sealed by flame under argon atmosphere, and the polymerization was conducted under irradiation with blue LED light (λ_{max} = 460 nm, 15.0 mW/cm^2) at room temperature, the stirring rate is 800 r/min and the temperature was controlled by mechanical ventilation and monitored by thermal imager. After the scheduled time, the ampoule was broken and the polymer solution was precipitated in hexane, and then the resultant polymer was obtained by filtration and vacuum drying.

1.3. Synthesis of P(BMA-*co*-HEMA)-*g*-PVL graft copolymer via ROP in a batch reactor

A typical polymerization protocol for the synthesis of P(BMA-*co*-HEMA)-*g*-PVL with a molar ratio of $[VL]_0/[\text{-OH}]_0/[TBD]_0$ = 10/1/0.5 was as follows. $[\text{-OH}]_0$ represented the concentration of repeated HEMA unit in P(BMA-*co*-HEMA) macroinitiator. Unpurified P(BMA-*co*-HEMA) macroinitiator, VL, and catalyst were directly added into the glass bottle equipped with a stir bar with a molar ratio of under argon atmosphere in the dark at room temperature, the stirring rate is 800 r/min and the temperature was controlled by mechanical ventilation and monitored by thermal imager. After the scheduled time, the glass bottle was opened and the polymerization was quenched by benzoic acid, and then the polymerization solution was precipitated in hexane. The resultant graft copolymer was obtained by filtration and vacuum drying.

1.4. Synthesis of P(BMA-*co*-HEMA) copolymer via photocontrolled BIT-RDRP in a continuous tube reactor

A typical polymerization protocol for the synthesis of P(BMA-*co*-HEMA) with a molar ratio of $[BMA]_0/[HEMA]_0/[EBPA]_0/[NaI]_0/[catalyst]_0$ = 50/50/2/10/2 was as follows. A homogeneous solution was prepared by mixing BMA (3736 μL, 23.28 mmol), HEMA (2919

μL, 23.28 mmol), EBPA (168.0 μL, 0.93 mmol), NaI (704.9 mg, 4.66 mmol), TEA (131.0 μL, 0.93 mmol), and DMSO (18.0 mL). Then the reaction solution was transferred into a test tube and sealed by a parafilm after deoxygenated by purging with argon for 30 minutes. The reaction solution was pumped directly into a transparent spiral quartz tube (inner diameter ID = 1.0 mm) under argon atmosphere, then the polymerization was conducted under irradiation with blue LED light (λ_{max} = 460 nm, 15.0 mW/cm^2) at room temperature, and the temperature was controlled by mechanical ventilation and monitored by thermal imager. The retention time (τ_1) was adjusted by changing the length of reaction tube (3.8 to 52.6 m) and flow rate (v_1 = 0.060 to 0.172 mL/min). The sample was collected into a test tube at the outlet of the first flow tube reactor, and was precipitated in hexane. Then, the resultant copolymer was obtained by filtration and vacuum drying.

1.5. Synthesis of P(BMA-*co*-HEMA)-*g*-PVL graft copolymer via ROP in a continuous tube reactor

The typical polymerization protocol for the synthesis of P(BMA-*co*-HEMA)-*g*-PVL with a molar ratio of $[VL]_0/[\text{-OH}]_0/[TBD]_0$ = 10/1/0.5 was as follows. The P(BMA-*co*-HEMA) stock solution without any purification process in the first tube, VL, and TBD under argon atmosphere were joined together by a mixer and flowed into the second quartz tube (ID = 1.0 mm), then the polymerization was further conducted under dark, and the temperature was controlled by mechanical ventilation and monitored by thermal imager. Their feed flow rate (v_1 = 0.12 mL/min and v_2 = 0.36 mL/min) remained unchanged to assure constant polymerization conditions. The retention time (τ_2) was controlled by changing the length of the second flow tube reactor (4.6 to 41.3 m). The sample was collected into a test tube at the outlet of the second quartz tube, and was precipitated in hexane. Then, the resultant copolymer was obtained by filtration and vacuum drying.

1.6. Characterizations

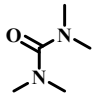
The number-average molar mass ($M_{n,GPC}$) and dispersity ($Đ$) of the resulting polymers were measured by TOSOH-HLC-8320 size exclusion chromatograph (SEC) equipped with a refractive index detector (Waters 2414) using TSK gel Super AWM-H columns (4.6 mm I.D. × 15 cm × 2) with measurable molar mass ranging from 1 × 10^3 to 1 × 10^5 g mol^{-1}. DMF (with 0.1 wt% LiBr) was used as the eluent at a flow rate of 0.35 mL min^{-1} at 40 °C. All the

GPC samples were injected using a TOSOH plus autosampler and were calibrated with PS standards obtained from TOSOH. The structures of macroinitiators and corresponding graft copolymers and HSQC NMR were characterized by nuclear magnetic resonance (Bruker, 300 MHz) using DMSO-d_6 or $CDCl_3$ as deuterated reagent and tetramethylsilane (TMS) as the internal standard at room temperature (25 °C). The DOSY NMR spectroscopy was performed on an Agilent DD2 600-MHz spectrometer equipped with four RF channels.

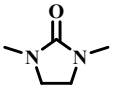
Grafting efficiency was estimated through the changes of integration area ratio between methylene protons of CH_2OH from HEMA units at 3.6 ppm and methyl protons from BMA and HEMA units at 1.0-0.4 ppm before and after graft-from process.

2. Additional Tables and Figures

Table S1. Effect of solvents on the copolymerization of BMA and HEMA in a batch reactor.[a]


TMU


DMSO


DMI


NMP


DMF


Toluene

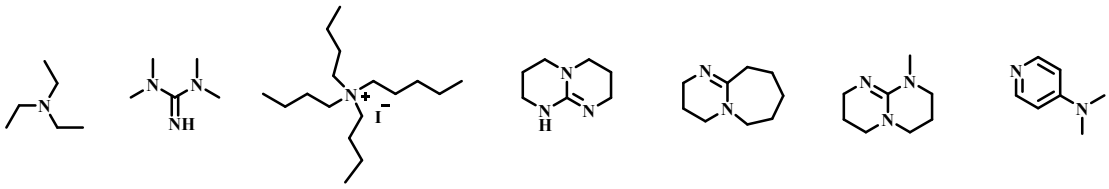

DCM


Dioxane

Entry	Solvent	R	[b]*Conv.* (%) BMA/HEMA	$M_{n,th}$ (g/mol)	[c]$M_{n,GPC}$ (g/mol)	[c]*Đ*
1	TMU	50/50/2/10	82.0/81.7	5900	10000	1.18
2	DMSO	50/50/2/10	71.6/72.5	5200	8500	1.15
3	DMI	50/50/2/10	74.8/72.2	5300	8700	1.12
4	NMP	50/50/2/10	72.2/70.3	5100	9000	1.26
5	DMF	50/50/2/10	39.4/38.4	2900	6000	1.14
6	PhMe	50/50/2/10	82.7/28.7	4200	5500	1.33
7	DCM	50/50/2/10	31.2/10.2	1700	2100	1.18
8	Dioxane	50/50/2/10	--/--	--	--	--

[a]Polymerization conditions: R = $[BMA]_0/[HEMA]_0/[EBPA]_0/[NaI]_0$, time = 11 h, under irradiation with blue LED light (λ_{max} = 460 nm, 15 mW/cm^2) at room temperature. [b]Determined by ^{1}H NMR. $M_{n,th} = [BMA]_0/[EBPA]_0 \times M_{BMA} \times Conv._{BMA} + [HEMA]_0/[EBPA]_0 \times M_{HEMA} \times Conv._{HEMA} + M_{EIPA}$. [c]$M_{n,GPC}$ and *Đ* were determined by GPC with PS standards in DMF (with 0.1 wt% LiBr).

Table S2. Effect of catalysts on the copolymerization of BMA and HEMA in a batch reactor.[a]



TEA TMG TBAI TBD DBU MTBD DMAP

Entry	Catalyst	R	[b]*Conv.* (%) BMA/HEMA	$M_{n,th}$ (g/mol)	[c]$M_{n,GPC}$ (g/mol)	[c]*Đ*
1	--	50/50/2/10/0	35.4 /32.6	2600	4200	1.10
2	TEA	50/50/2/10/2	62.3/70.2	4800	8900	1.22
3	TMG	50/50/2/10/2	73.6/84.8	5700	17800	1.52
4	TBAI	50/50/2/10/2	32.2/30.1	2400	3900	1.24
5	TBD	50/50/2/10/2	--/--	--	--	--
6	DBU	50/50/2/10/2	55.6/53.2	4000	7800	1.32
7	MTBD	50/50/2/10/2	69.3/70.1	**5000**	9200	1.30
8	DMAP	50/50/2/10/2	36.2/40.2	2900	5100	1.28

[a] Polymerization conditions: R = $[BMA]_0/[HEMA]_0/[EBPA]_0/[NaI]_0/[Catalyst]_0$, $V_{Monomers}/V_{DMSO}$= 1/2, time = 7 h, under irradiation with blue LED light (λ_{max} = 460 nm, 15 mW/cm^2) at room temperature. [b]Determined by ^{1}H NMR. $M_{n,th}$ = $[BMA]_0/[EBPA]_0 \times M_{BMA} \times Conv._{BMA}$ + $[HEMA]_0/[EBPA]_0 \times M_{HEMA} \times Conv._{HEMA} + M_{EIPA}$. [c]$M_{n,GPC}$ and *Đ* were determined by GPC with PS standards in DMF (with 0.1 wt% LiBr).

Table S3. Effect of flow rate on the copolymerization of BMA and HEMA in a continuous tube reactor. [a]

Entry	Flow rate (mL/min)	[b]*Conv.* (%) BMA/HEMA	$M_{n,th}$ (g/mol)	[c]$M_{n,GPC}$ (g/mol)	[c]$Đ$
1	0.060	64.3/59.2	4500	8200	1.18
2	0.072	71.8/65.6	5000	9000	1.25
3	0.096	81.6/79.8	5800	10300	1.22
4	0.120	87.8/85.2	6200	12400	1.20
5	0.172	88.1/85.6	6200	12000	1.22

[a] Polymerization conditions: R = $[BMA]_0/[HEMA]_0/[EBPA]_0/[NaI]_0/[TEA]_0$ = 50/50/2/10/2, $V_{monomers}/V_{DMSO}$ = 1/2, τ_1 = 480.0 min, under irradiation with blue LED light (λ_{max} = 460 nm, 15 mW/cm^2) at room temperature. [b]Determined by ^{1}H NMR. [c]Determined by GPC with PS standards in DMF (with 0.1 wt% LiBr). $M_{n,th} = [BMA]_0/[EBPA]_0 \times M_{BMA} \times Conv._{BMA} + [HEMA]_0/[EBPA]_0 \times M_{HEMA} \times Conv._{HEMA} + M_{EIPA}$.

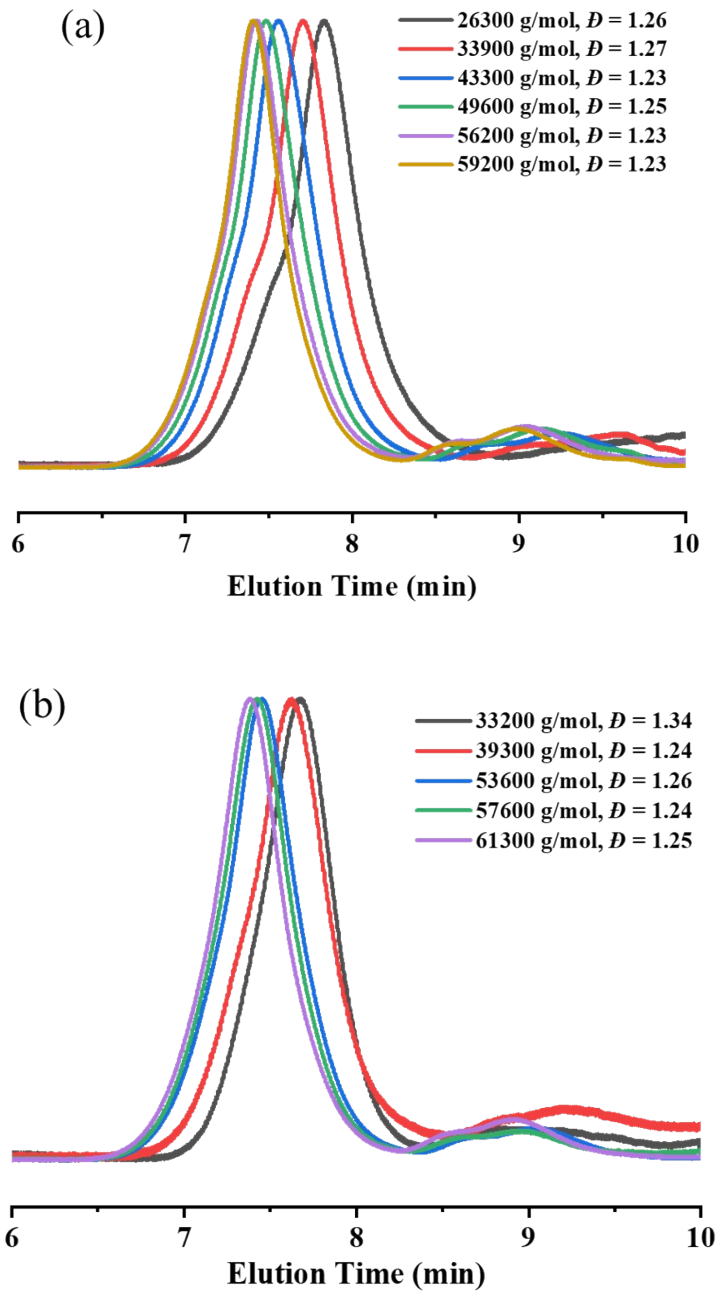


Fig. S1 GPC curves of P(BMA-*co*-HEMA)-*g*-PVL corresponding to different polymerization times for the ROP using P(BMA-*co*-HEMA) as macroinitiator ($M_{n,GPC}$ = 13800 g/mol, $Đ$ = 1.25) in (a) batch and (b) flow reactor. Polymerization conditions in quartz pipe: R_1 = $[BMA]_0/[HEMA]_0/[EBPA]_0/[NaI]_0/[TEA]_0$ = 50/50/2/10/2, under irradiation with blue LED light (λ_{max} = 465 nm, 15 mW/cm^2) at room temperature, monomer concentration = 27.0 v % in DMSO, v_1 = 0.120 mL/min, quartz pipe with ID = 1.0 mm and OD = 3.0 mm, the pipe length = 73 m. R_2 = $[VL]_0/[\text{-OH}]_0$, v_2 = 0.36 mL/min, in the dark, at room temperature, quartz pipe with ID = 1.0 mm and OD = 3.0 mm, the pipe length = 4.6, 9.2, 13.8, 22.9, 27.5 m. $[\text{-OH}]_0$ represented the concentration of repeated HEMA unit in P(BMA-*co*-HEMA) macroinitiator.

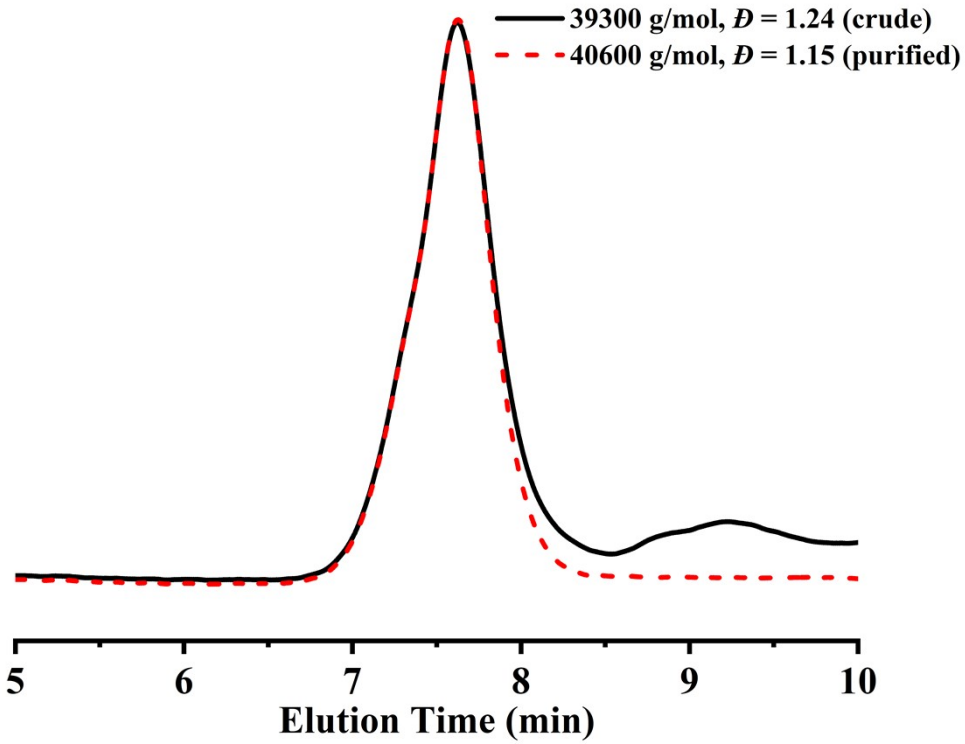


Fig. S2 GPC curves of P(BMA-*co*-HEMA)-*g*-PVL before and after purification.

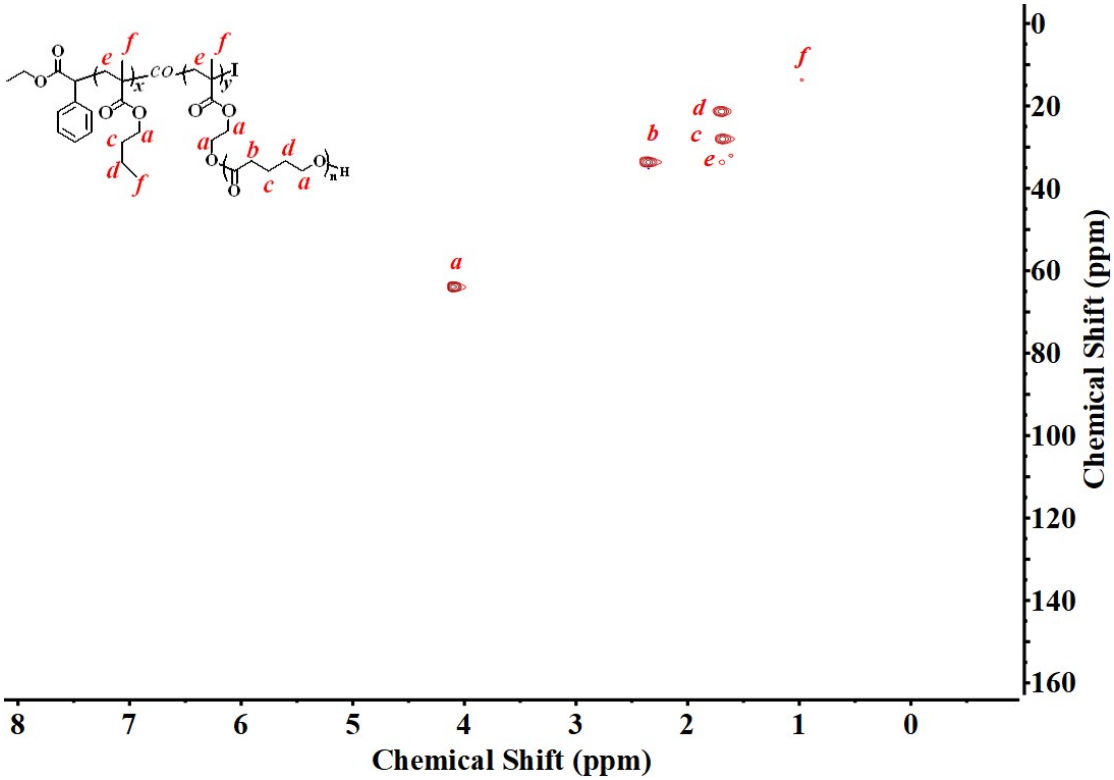


Fig. S3 HSQC NMR spectrum of P(BMA-*co*-HEMA)-*g*-PVL.

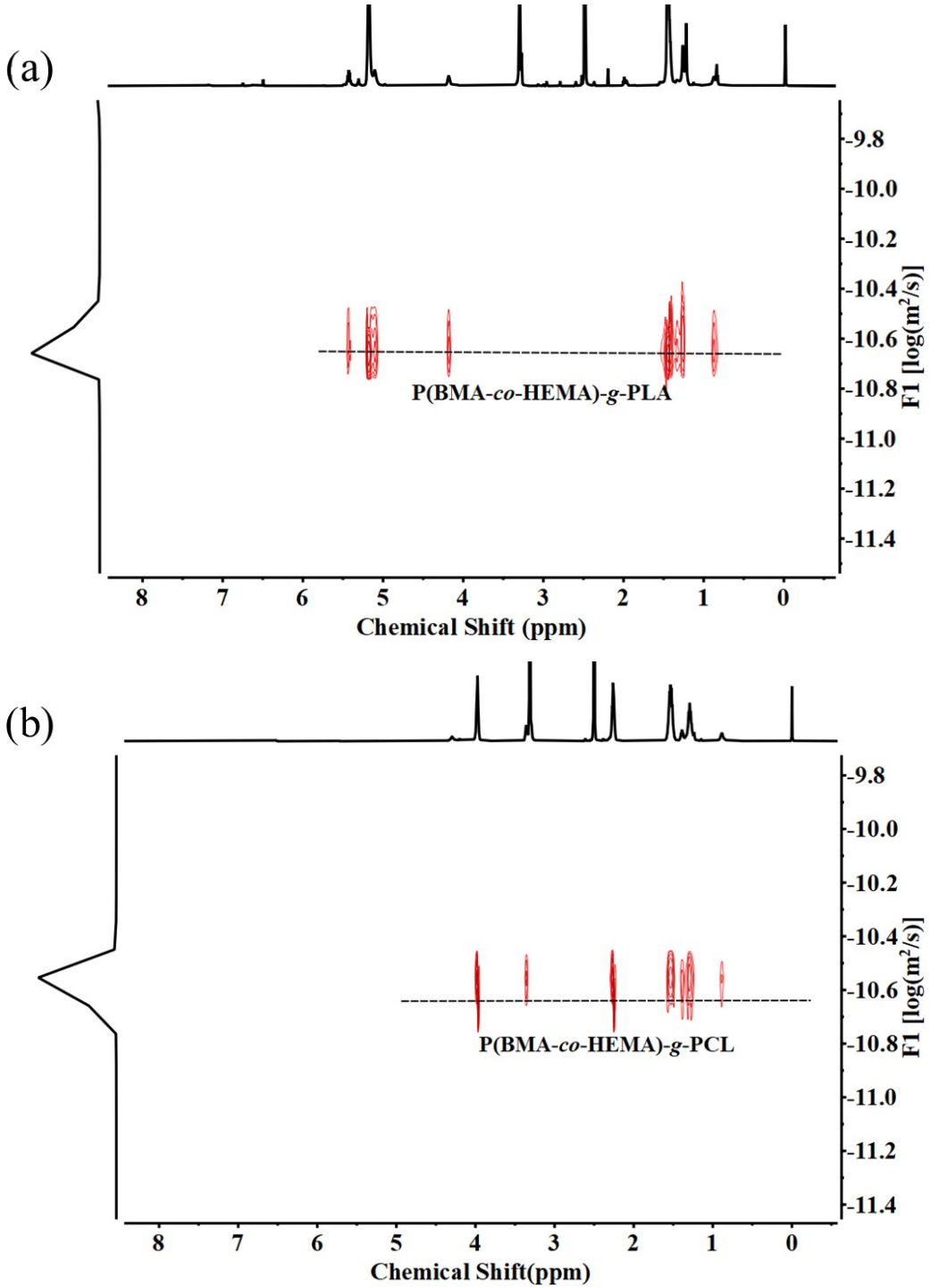


Fig. S4 DOSY NMR spectra of the (a) P(BMA-*co*-HEMA)-*g*-PLA and (b) P(BMA-*co*-HEMA)-*g*-PCL synthesized in flow tube reactor in DMSO-d_6. Polymerization conditions: R_1 = $[BMA]_0/[HEMA]_0/[EBPA]_0/[NaI]_0/[TEA]_0$ = 50/50/2/10/2, v_1 = 0.120 mL/min, τ_1 = 480.0 min, under irradiation with blue LED light (λ_{max} = 465 nm, 15 mW/cm^2) at room temperature; v_2 = 0.36 mL/min, τ_2 = 90.0 min, in the dark, at room temperature.

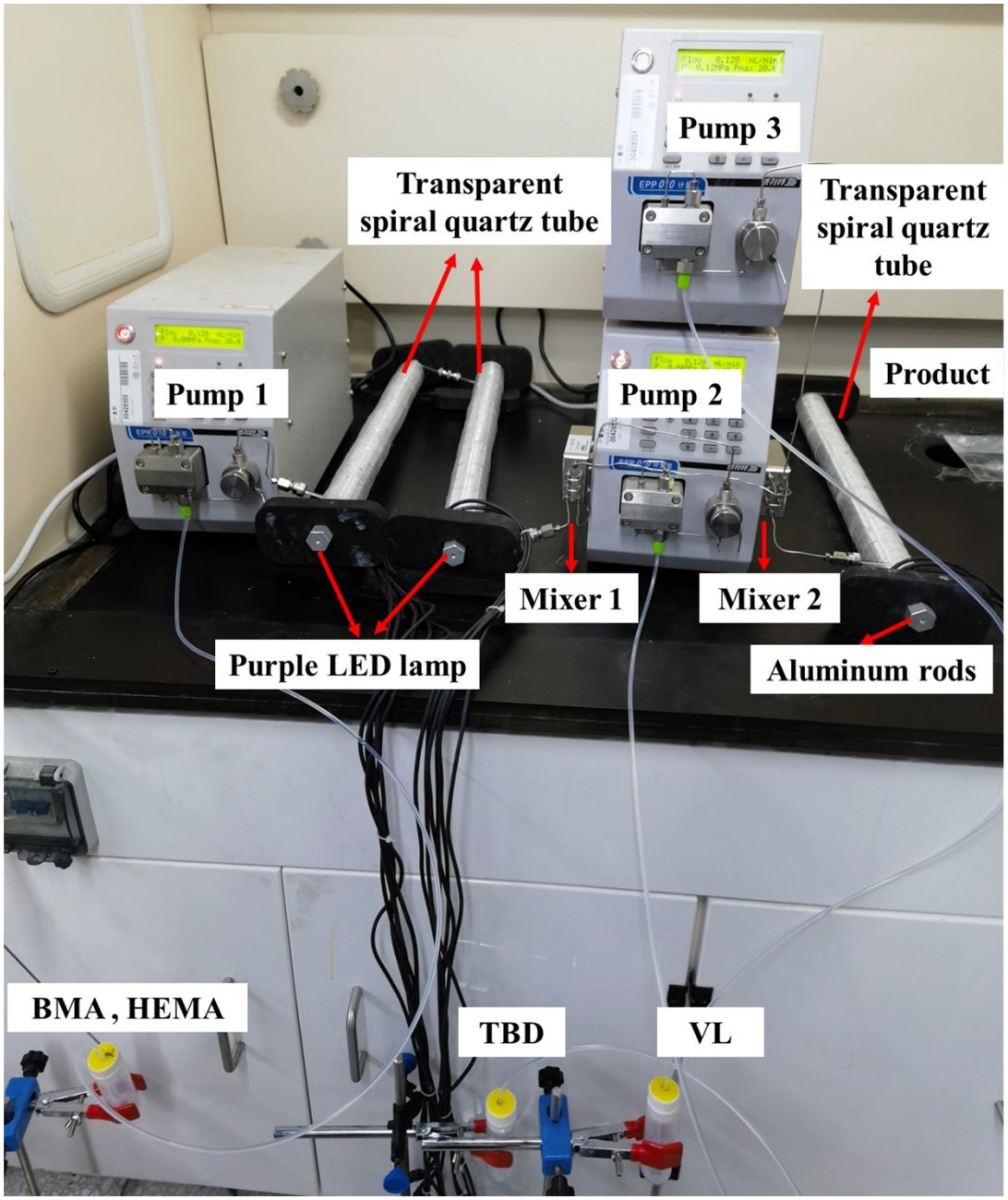


Fig. S5 Photograph of continuous flow setup for preparation of grafted polyesters through successive photocontrolled BIT-RDRP and ROP strategy at room temperature. The temperature was controlled by mechanical ventilation and monitored by thermal imager.