Electronic Supplementary Information

Exergetic life cycle analysis for the selection of chromatographic separation processes in the pharmaceutical industry: Preparative HPLC versus Preparative SFC.

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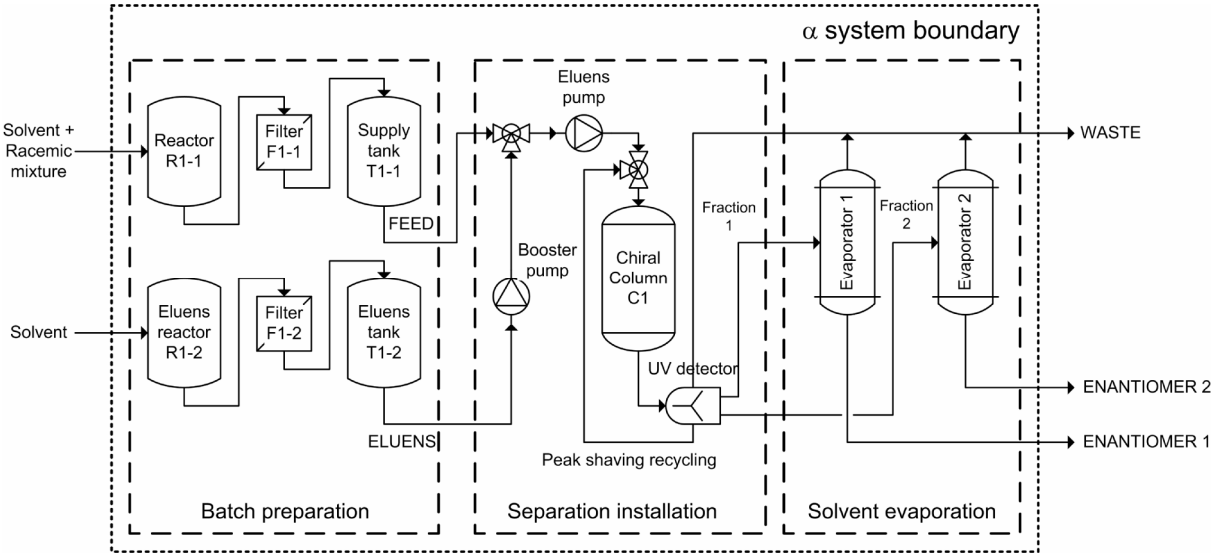

Figure S1: P&ID of the Prep-HPLC separation in the α system boundary (energy streams are not shown to reduce complexity)

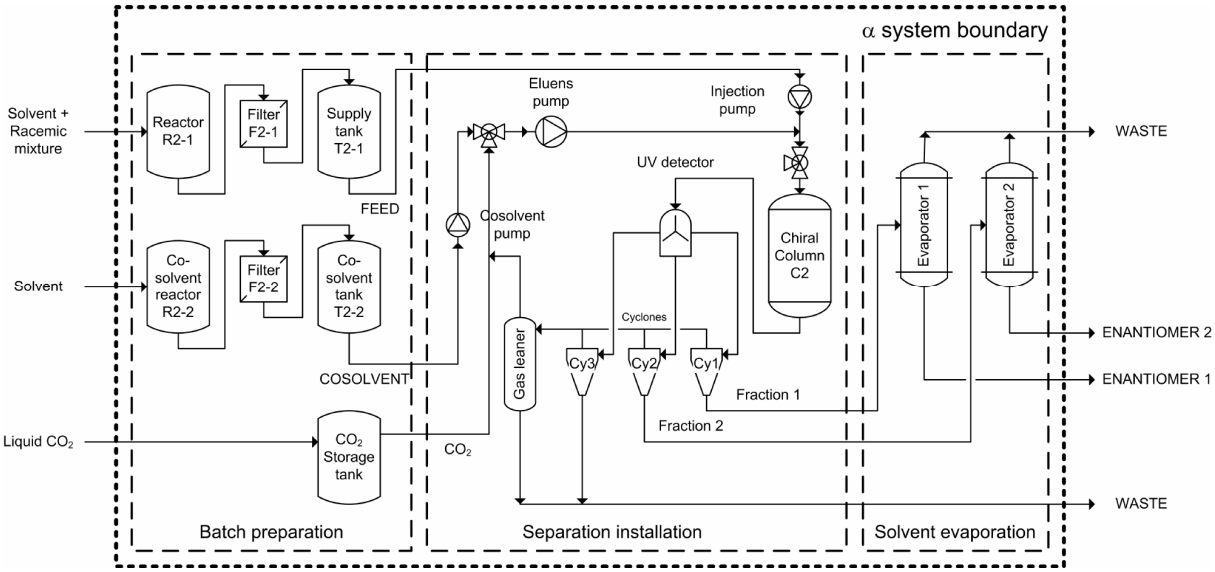

Figure S2: P&ID of the Prep-SFC separation in the α system boundary (energy streams are not shown to reduce complexity)

Table S1: Mass and energy balance in the α system boundary for the Prep-HPLC separation of 500 g racemic mixture. This table is linked with the annotations in Fig. S1

Equipment BASIC OPERATIONS	INPUT		OUTPUT	
Reactor R1-1				
Inerting	68.75 kJ	Electricity for setting vacuum		
	0.20 kg	N_2 gas at 8 bar		
Pumping in solvents + racemic mixture	57.29 kJ	Electricity for pumping solvents	0.20 kg	N_2
	0.50 kg	Racemic mixture		
	26.03 kg	Methanol		
	63.69 kg	Ethanol		
	0.07 kg	N_2 gas at 8 bar		
Stirring	511.50 kJ	Electricity for stirring		
Emptying reactor	0.00 kJ	Gravimetrically	90.22 kg	Solvents + racemic mixture to F1-1
			0.07 kg	N_2
Cleaning reactor	1.67 kg	Water	1.67 kg	Water
	1.23 kg	Methanol	1.23 kg	Methanol
	10.66 kJ	Electricity for pumping solvents		
	495.00 kJ	Electricity for stirring		
	747.48 kJ	Heat from shellsol (175°C, 6 bar)		
	190.12 kJ	Electricity for pumping heating medium		
	747.48 kJ	Cooling with cold shellsol (4°C, 6 bar)		
Filter F1-1				
Inerting	495.00 kJ	Electricity for setting vacuum		
	0.34 kg	N_2 gas at 8 bar		
Pumping in mixture	90.22 kg	Solvents + racemic mixture from R1-1	0.13 kg	N_2
Filtration under pressure	0.63 kg	N_2 gas at 8 bar	90.22 kg	Solvent + racemic mixture to T1-1
Emptying filter	0.00 kJ	Manually	0.85 kg	N_2
Cleaning filter	4.00 kg	Water	4.00 kg	Water
	3.95 kg	Methanol	3.95 kg	Methanol
	29.70 kJ	Electricity for pumping solvents		
	1350.00 kJ	Electricity for stirring		
	4755.62 kJ	Heat from shellsol (175°C, 6 bar)		
	675.00 kJ	Electricity for pumping heating medium		
	4755.62 kJ	Cooling with cold shellsol (4°C, 6 bar)		
Supply tank T1-1				
Inerting	68.75 kJ	Electricity for setting vacuum		
	0.20 kg	N_2 gas at 8 bar		
Pumping in mixture	90.22 kg	Filtered solvents + racemic mixture from F1-1	0.13 kg	N_2
Emptying tank	0.00 kJ	Gravimetrically	90.22 kg	Solvents + racemic mixture to C1
			0.07 kg	N_2
Cleaning tank	1.67 kg	Water	1.67 kg	Water
	0.99 kg	Methanol	0.99 kg	Methanol
	0.07 kg	Acetone	0.07 kg	Acetone
	28.65 kJ	Electricity for pumping solvents		
Eluens reactor R1-2				
Inerting	330.00 kJ	Electricity for setting vacuum		
	0.97 kg	N_2 gas at 8 bar		
Pumping in solvents	419.63 kg	Methanol	0.97 kg	N_2
	33.69 kg	Acetonitrile		
	0.20 kg	Trifluoroacetic acid		
	0.13 kg	Water		
	275.00 kJ	Electricity for pumping solvents		
	0.32 kg	N_2 gas at 8 bar		
Stirring	5160.00 kJ	Electricity for stirring		
Emptying reactor	0.00 kJ	Gravimetrically	453.64 kg	Solvents to F1-2
			0.32 kg	N_2
Cleaning reactor	8.00 kg	Water	8.00 kg	Water
	5.93 kg	Methanol	5.93 kg	Methanol
	51.15 kJ	Electricity for pumping solvents		
	1620.00 kJ	Electricity for stirring		
	3587.91 kJ	Heat from shellsol (175°C, 6 bar)		
	402.30 kJ	Electricity for pumping heating medium		
	3587.91 kJ	Cooling with cold shellsol (4°C, 6 bar)		

Filter F1-2

Inerting	990.00	kJ	Electricity for setting vacuum		
	0.69	kg	N_2 gas at 8 bar		
Pumping in mixture	453.64	kg	Solvents from R1-2	0.66	kg N_2
Filtration under pressure	1.67	kg	N_2 gas at 8 bar	453.64	kg Solvent to T1-2
Emptying filter	0.00	kJ	Manually	1.70	kg N_2
Cleaning filter	8.00	kg	Water	8.00	kg Water
	7.90	kg	Methanol	7.90	kg Methanol
	59.40	kJ	Electricity for pumping solvents		
	2700.00	kJ	Electricity for stirring		
	9511.24	kJ	Heat from shellsol (175°C, 6 bar)		
	1350.00	kJ	Electricity for pumping heating medium		
	9511.24	kJ	Cooling with cold shellsol (4°C, 6 bar)		

Eluens tank T1-2

Inerting	330.00	kJ	Electricity for setting vacuum		
	0.97	kg	N_2 gas at 8 bar		
Pumping in mixture	453.64	kg	Filtered solvents F1-2	0.66	kg N_2
Emptying tank	0.00	kJ	Gravimetrically	453.64	kg Eluens to C1
				0.32	kg N_2
Cleaning tank	8.00	kg	Water	8.00	kg Water
	4.74	kg	Methanol	4.74	kg Methanol
	0.32	kg	Acetone	0.32	kg Acetone
	137.52	kJ	Electricity for pumping solvents		

Column C1

Conditioning	9900.00	kJ	Electricity for pumping		
	8532.00	kJ	Heating with steam (175°C, 9 bar)		
Separation	1392405.06	kJ	Electricity for pumping	47.51	kg Waste fraction
	543.86	kg	Solution	of which 0.05	kg racemic mixture
	of which 0.50	kg	racemic mixture	and 47.46	kg solvent mixture
	and 543.36	kg	solvent mixture	198.75	kg Fraction 1 to E1-1
	1200000.00	kJ	Heating with steam (175°C, 9 bar)	of which 0.225	kg enantiomer 1
				and 198.52	kg solvent mixture
				297.61	kg Fraction 2 to E1-2
				of which 0.225	kg enantiomer 1
				and 297.39	kg solvent mixture
Cleaning	9900.00	kJ	Electricity for pumping	67.10	kg Ethanol
	67.10	kg	Ethanol		
	8532.00	kJ	Heating with steam (175°C, 9 bar)		

Evaporator E1-1

Inerting	67.50	kJ	Electricity for setting vacuum		
	0.01	kg	N_2 gas at 8 bar		
Inserting fraction 1	198.75	kg	Fraction 1	0.01	kg N_2
	of which 0.23	kg	enantiomer 1		
	and 198.52	kg	solvent mixture		
Heating up from 30 °C to 55 °C	220679.46	kJ	Heat from warm water (60°C)		
	5575.32	kJ	Electricity for pumping warm water		
Creating vacuüm	316.46	kJ	Electricity for pumping	198.52	kg Solvent mixture
	220679.46	kJ	Cooling with cooling water (4°C)		
Scraping	13924.05	kJ	Electricity for the scraper		
Emtying evaporator	0.00	kJ	Manually	0.225	kg Enantiomer 1
Cleaning evaporator	0.90	kg	Ethylacetate	0.90	kg Ethylacetate
	1.99	kg	Dichloromethane / methanol	1.99	kg Dichloromethane / methanol
	0.79	kg	Ethanol	0.79	kg Ethanol
	2591.45	kJ	Heat from warm water (60°C)		
	103.18	kJ	Electricity for pumping warm water		
	206.35	kJ	Electricity for the scraper		
	2591.45	kJ	Cooling with cooling water (4°C)		

Evaporator E2-2

Inerting	67.50	kJ	Electricity for setting vacuum		
	0.01	kg	N_2 gas at 8 bar		
Inserting fraction 2	297.61	kg	Fraction 2	0.01	kg N2
	of which 0.23	kg	enantiomer 2		
	and 297.39	kg	solvent mixture		
Heating up from 30 °C to 55 °C	330572.69	kJ	Heat from warm water (60°C)		
	8348.73	kJ	Electricity for pumping warm water		
Creating vacuüm	316.46	kJ	Electricity for pumping	297.39	kg Solvent mixture
	330572.69	kJ	Cooling with cooling water (4°C)		
Scraping	13924.05	kJ	Electricity for the scraper		
Emtying evaporator	0.00	kJ	Manually	0.225	kg Enantiomer 2
Cleaning evaporator	0.90	kg	Ethylacetate	0.90	kg Ethylacetate
	1.99	kg	Dichloromethane / methanol	1.99	kg Dichloromethane / methanol
	0.79	kg	Ethanol	0.79	kg Ethanol
	2591.45	kJ	Heat from warm water (60°C)		
	103.18	kJ	Electricity for pumping warm water		
	206.35	kJ	Electricity for the scraper		
	2591.45	kJ	Cooling with cooling water (4°C)		

Tabel S2: Mass and energy balance in the α system boundary for the Prep-SFC separation of 500 g racemic mixture. This table is linked with the annotations in Fig. S2

Equipment BASIC OPERATIONS	INPUT		OUTPUT	
Reactor R2-1				
Inerting	68.75 kJ	Electricity for setting vacuum		
	0.20 kg	N_2 gas at 8 bar		
Pumping in solvents + racemic mixture	57.29 kJ	Electricity for pumping solvents	0.20 kg	N_2
	0.50 kg	Racemic mixture		
	4.58 kg	Methanol		
	11.21 kg	Ethanol		
	0.18 kg	N_2 gas at 8 bar		
Stirring	90.00 kJ	Electricity for stirring		
Emptying reactor	0.00 kJ	Gravimetrically	16.29 kg	Solvents + racemic mixture to F2-1
			0.18 kg	N_2
Cleaning reactor	1.67 kg	Water	1.67 kg	Water
	1.23 kg	Methanol	1.23 kg	Methanol
	10.66 kJ	Electricity for pumping solvents		
	495.00 kJ	Electricity for stirring		
	747.48 kJ	Heat from shellsol (175°C, 6 bar)		
	190.12 kJ	Electricity for pumping heating medium		
	747.48 kJ	Cooling with cold shellsol (4°C, 6 bar)		
Filter F2-1				
Inerting	495.00 kJ	Electricity for setting vacuum		
	0.34 kg	N_2 gas at 8 bar		
Pumping in mixture	16.29 kg	Solvents + racemic mixture from R2-1	0.02 kg	N_2
Filtration under pressure	0.53 kg	N_2 gas at 8 bar	16.29 kg	Solvent + racemic mixture to T2-1
Emptying filter	0.00 kJ	Manually	0.85 kg	N_2
Cleaning filter	4.00 kg	Water	4.00 kg	Water
	3.95 kg	Methanol	3.95 kg	Methanol
	29.70 kJ	Electricity for pumping solvents		
	1350.00 kJ	Electricity for stirring		
	4755.62 kJ	Heat from shellsol (175°C, 6 bar)		
	675.00 kJ	Electricity for pumping heating medium		
	4755.62 kJ	Cooling with cold shellsol (4°C, 6 bar)		
Supply tank T2-1				
Inerting	68.75 kJ	Electricity for setting vacuum		
	0.20 kg	N_2 gas at 8 bar		
Pumping in mixture	16.29 kg	Filtered solvents + racemic mixture from F2-1	0.02 kg	N_2
Emptying tank	0.00 kJ	Gravimetrically	16.29 kg	Solvents + racemic mixture to C2
			0.18 kg	N_2
Cleaning tank	1.67 kg	Water	1.67 kg	Water
	0.99 kg	Methanol	0.99 kg	Methanol
	0.07 kg	Acetone	0.07 kg	Acetone
	23.40 kJ	Electricity for pumping solvents		
Cosolvent reactor R2-2				
Inerting	165.00 kJ	Electricity for setting vacuum		
	0.49 kg	N_2 gas at 8 bar		
Pumping in solvents	199.89 kg	Ethanol	0.49 kg	N_2
	137.50 kJ	Electricity for pumping solvents		
	0.20 kg	N_2 gas at 8 bar		
Stirring	1140.00 kJ	Electricity for stirring		
Emptying reactor	0.00 kJ	Gravimetrically	199.89 kg	Solvents to F2-2
			0.20 kg	N_2
Cleaning reactor	4.00 kg	Water	4.00 kg	Water
	2.96 kg	Methanol	2.96 kg	Methanol
	25.58 kJ	Electricity for pumping solvents		
	810.00 kJ	Electricity for stirring		
	1793.96 kJ	Heat from shellsol (175°C, 6 bar)		
	201.15 kJ	Electricity for pumping heating medium		
	1793.96 kJ	Cooling with cold shellsol (4°C, 6 bar)		

Filter F2-2

Inerting	495.00 kJ	Electricity for setting vacuum		
	0.34 kg	N_2 gas at 8 bar		
Pumping in mixture	199.89 kg	Solvents from R2-2	0.29 kg	N_2
Filtration under pressure	0.79 kg	N_2 gas at 8 bar	199.89 kg	Solvent to T2-2
Emptying filter	0.00 kJ	Manually	0.85 kg	N_2
Cleaning filter	4.00 kg	Water	4.00 kg	Water
	3.95 kg	Methanol	3.95 kg	Methanol
	29.70 kJ	Electricity for pumping solvents		
	1350.00 kJ	Electricity for stirring		
	4755.62 kJ	Heat from shellsol (175°C, 6 bar)		
	675.00 kJ	Electricity for pumping heating medium		
	4755.62 kJ	Cooling with cold shellsol (4°C, 6 bar)		

Cosolvent tank T2-2

Inerting	165.00 kJ	Electricity for setting vacuum		
	0.49 kg	N_2 gas at 8 bar		
Pumping in mixture	199.89 kg	Filtered solvents F2-2	0.29 kg	N_2
Emptying tank	0.00 kJ	Gravimetrically	199.89 kg	Eluens to C2
			0.20 kg	N_2
Cleaning tank	4.00 kg	Water	4.00 kg	Water
	2.37 kg	Methanol	2.37 kg	Methanol
	0.16 kg	Acetone	0.16 kg	Acetone
	65.46 kJ	Electricity for pumping solvents		

Column C2

Conditioning	19962.00 kJ	Electricity for pumping		
	34200.00 kJ	Electricity for heating		
	25200.00 kJ	Electricity for cooling		
Separation	1651575.00 kJ	Electricity for pumping	100.40 kg	Waste fraction
	216.19 kg	Solution + modifier	of which 0.03 kg	racemic mixture
	of which 0.50 kg	racemic mixture	and 100.38 kg	solvent mixture
	and 215.69 kg	organic solvent	44.27 kg	Fraction 1
	950.00 kg	CO_2 (60 bar, liquid)	of which 0.225 kg	enantiomer 1
	2850000.00 kJ	Electricity for heating	and 44.04 kg	solvent mixture
	2100000.00 kJ	Electricity for cooling	69.34 kg	Fraction 2
			of which 0.225 kg	enantiomer 1
			and 69.11 kg	solvent mixture
			950.00 kg	CO_2 (1 atm)
Cleaning	19800.00 kJ	Electricity for pumping	9.60 kg	Ethanol
	9.60 kg	Ethanol	9.60 kg	CO_2 (1 atm)
	9.60 kg	CO_2 (60 bar, liquid)		
	34200.00 kJ	Electricity for heating		
	25200.00 kJ	Electricity for cooling		

Evaporator E2-1

Inerting	67.50 kJ	Electricity for setting vacuum		
	0.01 kg	N_2 gas at 8 bar		
Inserting fraction 1	44.27 kg	Fraction 1	0.01 kg	N_2
	of which 0.23 kg	enantiomer 1		
	and 44.04 kg	solvent mixture		
Heating up from 30 °C to 55 °C	39810.54 kJ	Heat from warm water (60°C)		
	3214.77 kJ	Electricity for pumping warm water		
Creating vacuüm	187.50 kJ	Electricity for setting vacuum	44.04 kg	Solvent mixture
	39810.54 kJ	Cooling with cooling water (4°C)		
Scraping	8250.00 kJ	Electricity for the scraper		
Emtying evaporator	0.00 kJ	Manually	0.225 kg	Enantiomer 1
Cleaning evaporator	0.90 kg	Ethylacetate	0.90 kg	Ethylacetate
	1.99 kg	Dichloromethane / methanol	1.99 kg	Dichloromethane / methanol
	0.79 kg	Ethanol	0.79 kg	Ethanol
	2591.45 kJ	Heat from warm water (60°C)		
	103.18 kJ	Electricity for pumping warm water		
	206.35 kJ	Electricity for the scraper		
	2591.45 kJ	Cooling with cooling water (4°C)		

Evaporator E2-2

Inerting	67.50 kJ	Electricity for setting vacuum		
	0.01 kg	N_2 gas at 8 bar		
Inserting fraction 2	69.34 kg	Fraction 2	0.01 kg	N_2
	of which 0.23 kg	enantiomer 2		
	and 69.11 kg	solvent mixture		
Heating up from 30 °C to 55 °C	62461.92 kJ	Heat from warm water (60°C)		
	5035.23 kJ	Electricity for pumping warm water		
Creating vacuüm	187.50 kJ	Electricity for pumping	69.11 kg	Solvent mixture
	62461.92 kJ	Cooling with cooling water (4°C)		
Scraping	8250.00 kJ	Electricity for the scraper		
Emtying evaporator	0.00 kJ	Manually	0.225 kg	Enantiomer 2
Cleaning evaporator	0.90 kg	Ethylacetate	0.90 kg	Ethylacetate
	1.99 kg	Dichloromethane / methanol	1.99 kg	Dichloromethane / methanol
	0.79 kg	Ethanol	0.79 kg	Ethanol
	2591.45 kJ	Heat from warm water (60°C)		
	103.18 kJ	Electricity for pumping warm water		
	206.35 kJ	Electricity for the scraper		
	2591.45 kJ	Cooling with cooling water (4°C)		