Batch Production of Amino Acids

Introduction

This design involves the batch production of amino acids. The four amino acids being produced are L-aspartic acid, L-phenylalanine, L-lysine HCl, and L-leucine. These amino acids are primarily used as dietary supplements. However, L-aspartic acid and L-phenylalanine are the two main ingredients in the artificial sweetener aspartame.

Capstone Chemical Corporation requested the most profitable method(s) for producing the following amounts of the amino acids:

1. 1% of the world market of L-lysine HCl
2. 2.5% of the world market of L-leucine
3. 2.5% of the world market of L-aspartic acid
4. 2.5% of the world market of L-phenylalanine

The amino acid facility was designed to produce L-lysine and L-leucine (in the amounts shown above) in alternating campaigns throughout the year. However, the facility was also to have the capability to produce L-aspartic acid and L-phenylalanine, if the market fluctuates or if a potential buyer requests an immediate production of these two amino acids. The final design includes raw material needs, equipment schematics, equipment bare module costs, utilities needed for the process, waste treatment cost, a 5-year Monte Carlo Simulation using a 5-year MACRS Depreciation Method detailing payback periods, and net present value information for the proposed amino acid batch facility. In addition, a 3-dimensional drawing detailing the reactor design and a plot plan illustrating the plant layouts have been generated.

Results

Amino Acid Process Descriptions

Figure 1 is the process flow diagram for the amino acid facility corresponding to the stream tables given in Tables 1, 2, 3, 4. This figure and these stream tables represent only 1 of 19 reactors needed for the amino acid facility. The remaining reactors follow the same schematics with few exceptions, as discussed below.

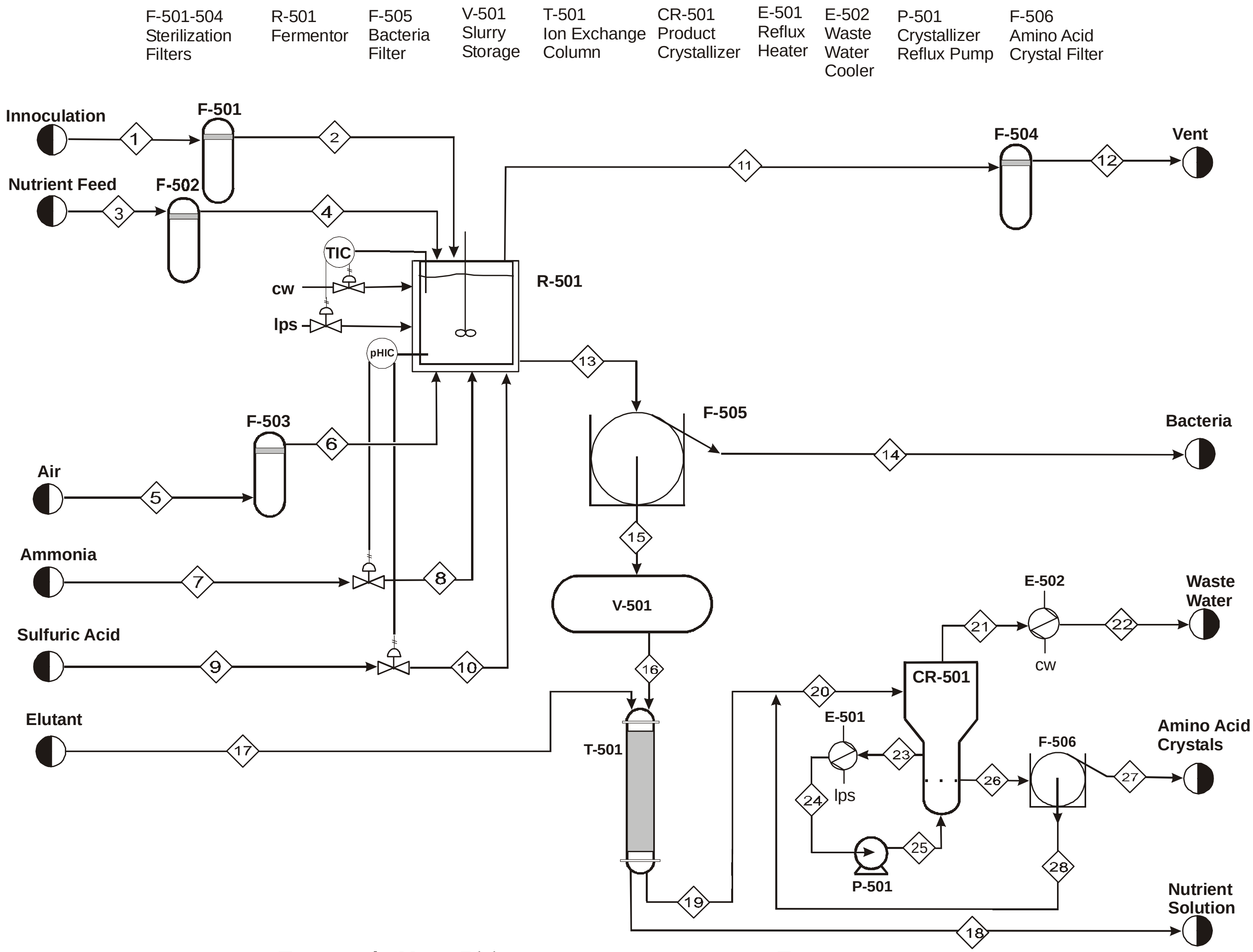


Figure 1: Unit 500 Amino Acid Process Flow Diagram

Table 1: Stream Tables for Leucine

Stream	1	2	3	4
Temp (°C)	30	30	30	30
Pressure (bar)	1	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	50	50	175,000	175,000
Flowrate (m^3/batch)	0.05	0.05	174.95	174.95
Component Flowrates				
Nutrient Media (kg/batch)	45	45	175,000	175,000
Biomass (kg/batch)	5	5	0	0
Eluting Water (kg/batch)	0	0	0	0
L-leucine (kg/batch)	0	0	0	0

Stream	13	14	15	16
Temp (°C)	30	30	30	30
Pressure (bar)	1	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	175,000	17,500	157,500	157,500
Flowrate (m^3/batch)	175	-	175	175
Component Flowrates				
Nutrient Media (kg/batch)	154,000	0	154,000	154,000
Biomass (kg/batch)	17,500	17,500	0	0
Eluting Water (kg/batch)	0	0	0	0
L-leucine (kg/batch)	3,500	0	3,500	3,500

Stream	17	18	19	20
Temp (°C)	70	30	70	70
Pressure (bar)	1	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	97,800	154,000	101,300	185,300
Flowrate (m^3/batch)	175	175	175	175
Component Flowrates				
Nutrient Media (kg/batch)	0	154,000	0	0
Biomass (kg/batch)	0	0	0	0
Eluting Water (kg/batch)	97,800	0	97,800	178,400
L-leucine (kg/batch)	0	0	3,500	6,900

Stream	21	22	23	24
Temp (°C)	100	25	100	100
Pressure (bar)	1	1	1	1
Vapor mole fraction	1	0	0	0
Flowrate (kg/batch)	96,700	96,700	170,200	170,200
Flowrate (m^3/batch)				
Component Flowrates				
Nutrient Media (kg/batch)	0	0	0	0
Biomass (kg/batch)	0	0	0	0
Eluting Water (kg/batch)	96,700	96,700	163,400	163,400
L-leucine (kg/batch)	0	0	6,800	6,800

Stream	25	26	27	28
Temp (°C)	100	100	100	100
Pressure (bar)	1	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	170,200	88,500	4,500	84,000
Flowrate (m^3/batch)				
Component Flowrates				
Nutrient Media (kg/batch)	0	0	0	0
Biomass (kg/batch)	0	0	0	0
Eluting Water (kg/batch)	163,400	81,700	1100	80,600
L-leucine (kg/batch)	6,800	3,400	0	3,400
L-leucine (solid) (kg/batch)	0	3,400	3,400	0

Table 2: Stream Tables for Lysine

Stream	1	2	3	4
Temp (°C)	30	30	30	30
Pressure (bar)	1	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	50	50	175,000	175,000
Flowrate (m^3/batch)	0.05	0.05	174.95	174.95
Component Flowrates				
Nutrient Media (kg/batch)	45	45	175,000	175,000
Biomass (kg/batch)	5	5	0	0
Eluting Water (kg/batch)	0	0	0	0
L- lysine (kg/batch)	0	0	0	0

Stream	13	14	15	16
Temp (°C)	30	30	30	30
Pressure (bar)	1	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	175,000	17,500	157,500	157,500
Flowrate (m^3/batch)	175	-	175	175
Component Flowrates				
Nutrient Media (kg/batch)	142,555	0	142,555	142,555
Biomass (kg/batch)	17,500	17,500	0	0
Eluting Water (kg/batch)	0	0	0	0
L- lysine (kg/batch)	14,945	0	14,945	14,945

Stream	17	18	19	20
Temp (°C)	70	30	70	70
Pressure (bar)	1	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	175,000	142,555	29,600	58,600
Flowrate (m^3/batch)	175	175	175	
Component Flowrates				
Nutrient Media (kg/batch)	0	142,555	0	0
Biomass (kg/batch)	0	0	0	0
Eluting Water (kg/batch)	175,000	0	12,200	27,400
L- lysine (kg/batch)	0	0	17,400	31,200

Stream	21	22	23	24
Temp (°C)	100	25	100	100
Pressure (bar)	1	1	1	1
Vapor mole fraction	1	0	0	0
Flowrate (kg/batch)	7,500	7,500	68,800	68,800
Flowrate (m^3/batch)				
Component Flowrates				
Nutrient Media (kg/batch)	0	0	0	0
Biomass (kg/batch)	0	0	0	0
Eluting Water (kg/batch)	7,500	7,500	36,000	36,000
L- lysine (kg/batch)	0	0	32,800	32,800

Stream	25	26	27	28
Temp (°C)	100	100	100	80
Pressure (bar)	2	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	68,800	50,800	19,300	29,000
Flowrate (m^3/batch)				
Component Flowrates				
Nutrient Media (kg/batch)	0	0	0	0
Biomass (kg/batch)	0	0	0	0
Eluting Water (kg/batch)	36,000	18,000	2,900	15,200
L-lysine (kg/batch)	32,800	16,400	2,600	13,800
L- lysine (solid) (kg/batch)	0	16,400	16,400	0

Table 3: Stream Tables for Aspartic Acid

Stream	1	2	3	4
Temp (°C)	30	30	30	30
Pressure (bar)	1	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	50	50	175,000	175,000
Flowrate (m^3/batch)	0.05	0.05	174.95	174.95
Component Flowrates				
Nutrient Media (kg/batch)	45	45	175,000	175,000
Biomass (kg/batch)	5	5	0	0
Eluting Water (kg/batch)	0	0	0	0
L- aspartic acid (kg/batch)	0	0	0	0

Stream	13	14	15	16
Temp (°C)	30	30	30	30
Pressure (bar)	1	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	175,000	17,500	157,500	157,500
Flowrate (m^3/batch)	175	-	175	175
Component Flowrates				
Nutrient Media (kg/batch)	138,880	0	138,880	138,880
Biomass (kg/batch)	17,500	17,500	0	0
Eluting Water (kg/batch)	0	0	0	0
L- aspartic acid (kg/batch)	18,620	0	18,620	18,620

Stream	17	18	19	20
Temp (°C)	70	30	70	70
Pressure (bar)	1	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	175,000	138,880	193,620	310,460
Flowrate (m^3/batch)	175	175	175	
Component Flowrates				
Nutrient Media (kg/batch)	0	138,880	0	0
Biomass (kg/batch)	0	0	0	0
Eluting Water (kg/batch)	175,000	0	175,000	273,220
L- aspartic acid (kg/batch)	0	0	18,620	37,240

Stream	21	22	23	24
Temp (°C)	100	25	100	100
Pressure (bar)	1	1	1	1
Vapor mole fraction	1	0	0	0
Flowrate (kg/batch)	70,600	70,600	246,040	246,040
Flowrate (m^3/batch)				
Component Flowrates				
Nutrient Media (kg/batch)	0	0	0	0
Biomass (kg/batch)	0	0	0	0
Eluting Water (kg/batch)	70,600	70,600	208,800	208,800
L- aspartic acid (kg/batch)	0	0	37,240	37,240

Stream	25	26	27	28
Temp (°C)	100	100	100	100
Pressure (bar)	2	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	246,040	141,640	24,800	116,840
Flowrate (m^3/batch)				
Component Flowrates				
Nutrient Media (kg/batch)	0	0	0	0
Biomass (kg/batch)	0	0	0	0
Eluting Water (kg/batch)	208,800	104,400	6,180	98,220
L- aspartic acid (kg/batch)	37,240	18,620	0	18,620
L-aspartic acid (solid) (kg/batch)		18,620	18,620	0

Table 4: Stream Tables for Phenylalanine

Stream	**1**	**2**	**3**	**4**
Temp (°C)	30	30	30	30
Pressure (bar)	1	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	50	50	175,000	175,000
Flowrate (m^3/batch)	0.05	0.05	174.95	174.95
Component Flowrates				
Nutrient Media (kg/batch)	45	45	175,000	175,000
Biomass (kg/batch)	5	5	0	0
Eluting Water (kg/batch)	0	0	0	0
L-phenylalanine (kg/batch)	0	0	0	0

Stream	**13**	**14**	**15**	**16**
Temp (°C)	30	30	30	30
Pressure (bar)	1	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	175,000	17,500	157,500	157,500
Flowrate (m^3/batch)	175	-	175	175
Component Flowrates				
Nutrient Media (kg/batch)	153,702	0	153,702	153,702
Biomass (kg/batch)	17,500	17,500	0	0
Eluting Water (kg/batch)	0	0	0	0
L-phenylalanine (kg/batch)	3,798	0	3,798	3,798

Stream	**17**	**18**	**19**	**20**
Temp (°C)	70	30	70	70
Pressure (bar)	1	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	69,000	153,702	72,800	110,600
Flowrate (m^3/batch)	175	175	175	
Component Flowrates				
Nutrient Media (kg/batch)	0	153,702	0	0
Biomass (kg/batch)	0	0	0	0
Eluting Water (kg/batch)	69,000	0	69,000	102,900
L-phenylalanine (kg/batch)	0	0	3,800	7,700

Stream	21	22	23	24
Temp (°C)	100	25	100	100
Pressure (bar)	1	1	1	1
Vapor mole fraction	1	0	0	0
Flowrate (kg/batch)	67,700	67,700	86,600	86,600
Flowrate (m^3/batch)				
Component Flowrates				
Nutrient Media (kg/batch)	0	0	0	0
Biomass (kg/batch)	0	0	0	0
Eluting Water (kg/batch)	67,700	67,700	78,600	78,600
L-phenylalanine (kg/batch)	0	0	8,000	8,000

Stream	25	26	27	28
Temp (°C)	100	100	100	100
Pressure (bar)	2	1	1	1
Vapor mole fraction	0	0	0	0
Flowrate (kg/batch)	86,600	47,100	9,300	37,800
Flowrate (m^3/batch)				
Component Flowrates				
Nutrient Media (kg/batch)	0	0	0	0
Biomass (kg/batch)	0	0	0	0
Eluting Water (kg/batch)	78,600	39,300	5,400	33,900
L-phenylalanine (kg/batch)	8,000	4,000	100	3,900
L-phenylalanine (solid) (kg/batch)	0	3,800	3,800	0

Reactors, R-501-519, operate in parallel. The kinetic data for the reactions can be found in References 1-4. The reactor effluent is then pumped to a series of rotary drum precoat filters. Here, the bacteria are filtered out of the slurry. The bacteria-free slurry is then sent to storage vessels, V-501-519. From the storage vessels, the slurry is pumped to ion exchange towers, T-501-516, where the amino acid is removed using an ion exchange resin. One resin, Dowex Marathon C, was chosen for use in the process. It is important to note that L-aspartic acid bypasses this section of the process, since it is crystallized in solution through precipitation. The ion exchange slurry is then sent to crystallizers CR-501-520. In this section, the amino acid is crystallized, using a series of Draft Tube Baffle (DTB) Crystallizers, precipitated out of solution, and filtered out of the slurry using rotary drum filters F-506-510. The amino acid product is then sent to the product storage area of the facility.

This amino acid facility is the most profitable design for producing at least 1% of the world market of L-lysine and 2.5% of the world market of L-leucine with the flexibility to produce approximately 2.5% of the world market of L-aspartic acid and L-phenylalanine upon demand. Table 5 shows the batch and process information for this facility.

Table 5: Batch and Process Information for the Amino Acid Facility

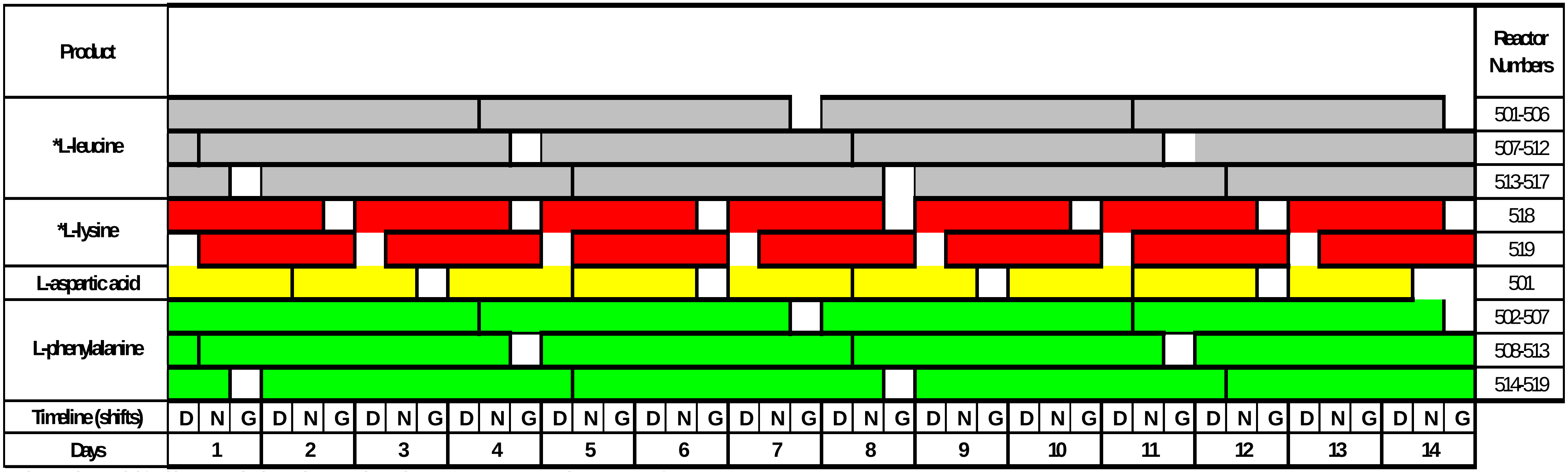
	L-leucine	**L-lysine**	**L-aspartic acid**	**L-phenylalanine**
World Demand (kg/y)	2.40×10^{8}	6.00×10^{8}	1.80×10^{7}	3.06×10^{8}
Amount Produced in Process (kg/y)	6.00×10^{6}	6.00×10^{6}	4.36×10^{6}	7.11×10^{6}
***Batch Time (h/batch)**	81	43	34	79
Concentration of Product (kg/m^3)	20	85.4	106.4	21.7
Total Volume for Year (m^3/y)	3.00×10^{5}	7.03×10^{4}	4.10×10^{4}	3.28×10^{5}
Required Number of Batches (batches/y)	104	182	234	104

*Includes cleaning time of 1 hour, tank filling/draining time of 3 hours, and graveyard shift times (time varies for each product illustrated in Figure 2).

Design Economics & Reactor Scheduling

The reactor schedule for the amino acid reactors is shown in Figure 2. This figure represents a recurring 14-day cycle, showing the schedule needed for all processes using all 19 reactors to produce either L-leucine and L-lysine or L-aspartic acid and L-phenylalanine. Figure 3 illustrates the 14-day separation schedule for the amino acid facility. The separation schedule was based upon the 14-day reactor schedule shown in Figure 2. There are four batches per cycle in the L-leucine and L-phenylalanine processes, seven for L-lysine, and nine for L-aspartic acid.

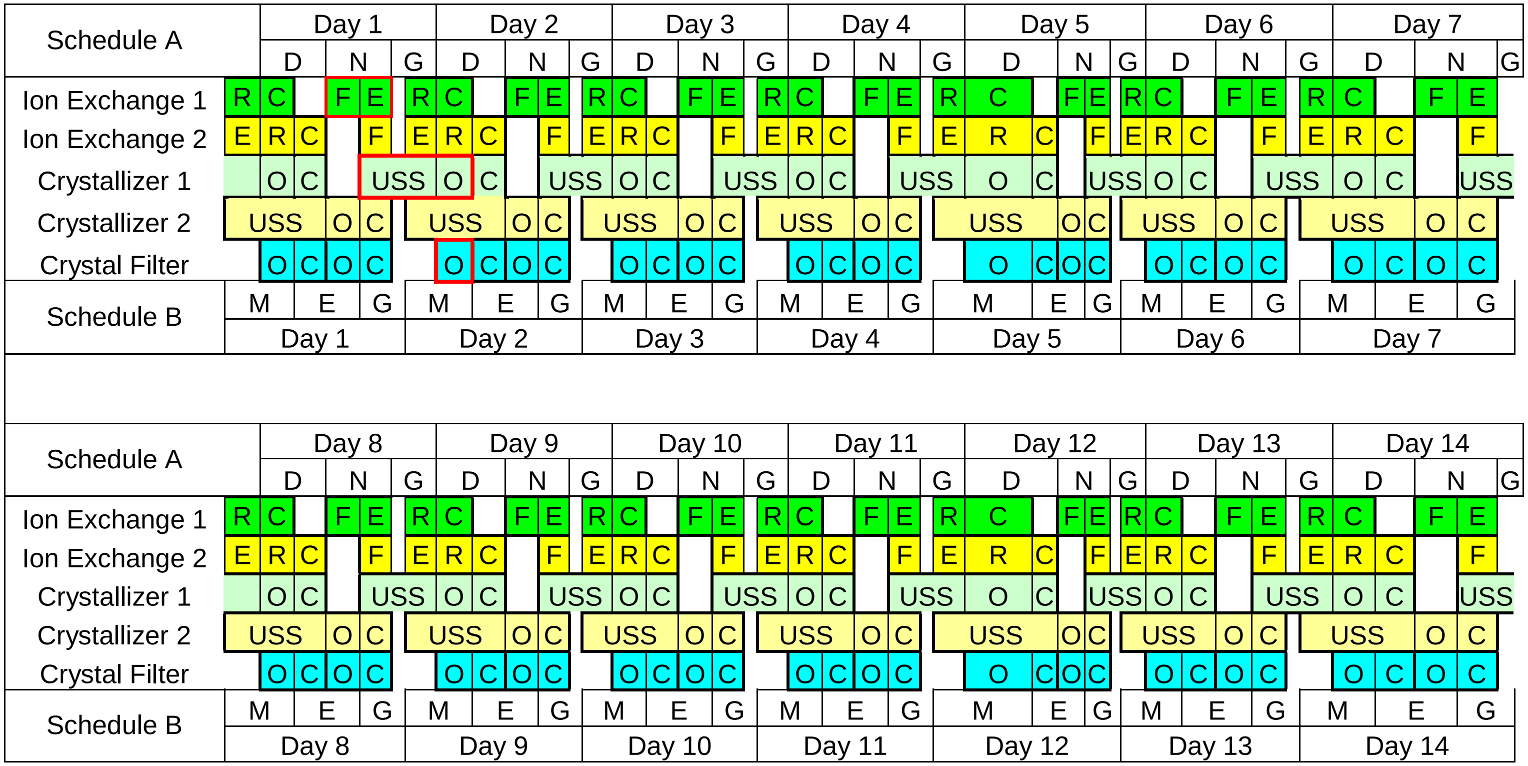
For the case when L-leucine and L-lysine are being produced, one of the reactors (R-517) in the L-leucine process does not operate for the entire year and has the schedule shown in Table 6. R-517 produces the last of the L-leucine and L-lysine in approximately 5700 hours and is idle for the remainder of the year. For the case when L-phenylalanine and L-aspartic acid are being produced, it is important to note that R-517 will produce L-phenylalanine all year as shown in Figure 2.



*The amino acid facility was designed to produce these 2 processes using a total of 19 reactors.

Note: D=daytime shift
N=Nightime shift
G=graveyard shift

Figure 2: Reactor Scheduling for the Amino Acid Process



Schedule A	Day Shift	8 AM to 4 PM
	Night Shift	4 PM to Midnight
	Graveyard A	Midnight to 8 AM
Schedule B	Morning Shift	4 AM to Noon
	Evening Shift	Noon to 8 PM
	Graveyard B	8 PM to 4 AM

F	Feeding Ion Exchange Column
E	Eluting Ion Exchange Column
R	Regenerating Ion Exchange Column
C	Cleaning Equipment
USS	Operating at Unsteady State
O	Operating at Steady State

Figure 3: Separation Scheduling for the Amino Acid Process

Table 6: Processing Time for Reactor-517 in L-leucine/L-lysine Process

Processing Time for Last Reactor in Each Process								
L-leucine and L-lysine	4073 hours (L-leucine)			1611 hours (L-lysine)				
Timeline (hours)	1000	2000	3000	4000	5000	6000	7000	8000

The break-even prices for the L-leucine and L-lysine processes are \$13.30/kg and \$2.70/kg, respectively. Figure 4 shows the yearly operating cost breakdown for these processes. Raw materials represent the largest cost followed by waste treatment and utility costs. A breakdown of the raw material cost for the L-leucine and L-lysine processes is shown in Figure 5. Figure 6 illustrates the equipment cost breakdown, and Figure 7 details the utility cost breakdown for these processes.

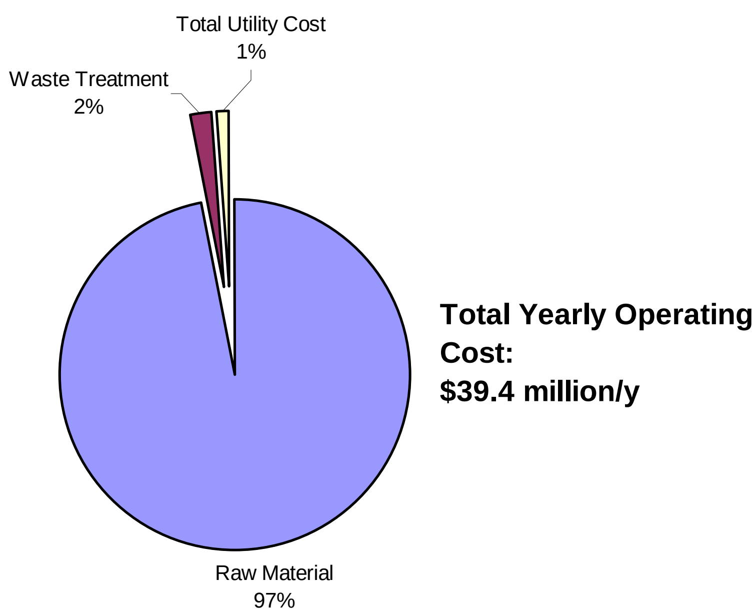


Figure 4: Yearly Operating Cost Breakdown for L-leucine and L-lysine

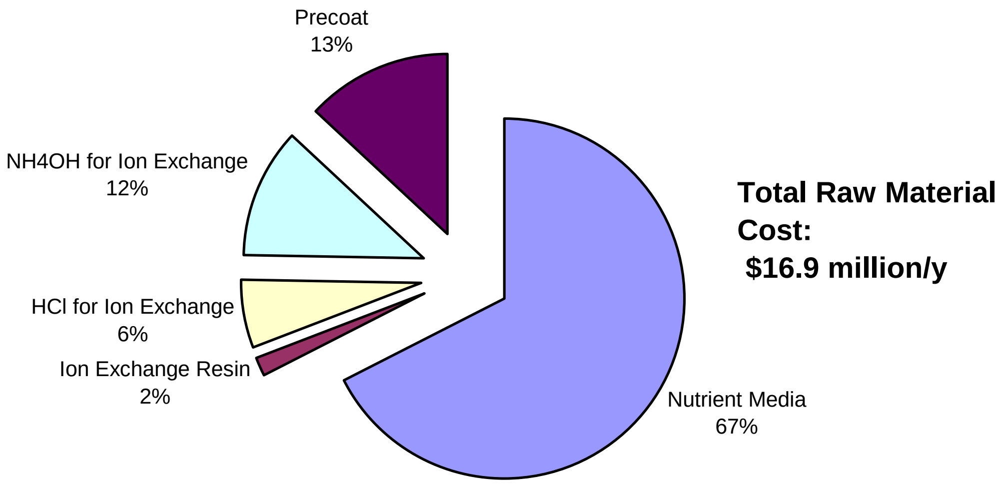


Figure 5: Raw Material Cost Breakdown for L-leucine and L-lysine

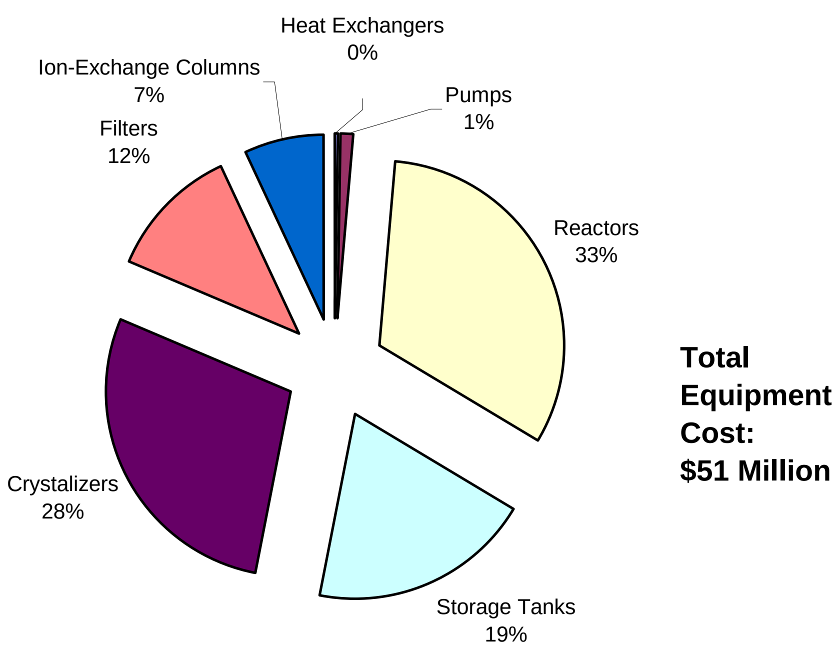


Figure 6: Total Equipment Cost Breakdown for L-leucine and L-lysine

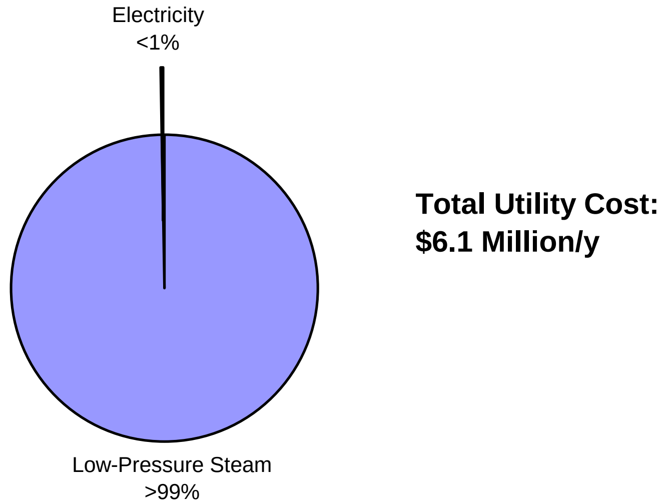


Figure 7: Total Utility Cost Breakdown for L-leucine and L-lysine

In order to run the L-phenylalanine and L-aspartic acid processes, additional equipment, not shown in Figure 1, must be purchased and is listed in Table 7.

Table 7: Additional Equipment Needed for L-phenylalanine and L-aspartic acid

L-aspartic Acid Process		
Equipment Type	**Number Required**	**Specifications**
Heat Exchangers	2	412 m^2
Centrifugal Pumps	8	2 kW
Crystal Filter	4	1.4 m^2
L-phenylalanine Process		
Equipment Type	**Number Required**	**Specifications**
Heat Exchangers	2	345 m^2

The break-even prices for the L-phenylalanine and L-aspartic acid processes are $15.00/kg and $12.00/kg, respectively. Figure 8 represents the yearly operating cost breakdown for these processes. A breakdown of raw material cost for the processes is shown in Figure 9. Figure 10 is the equipment cost breakdown, and Figure 11 details the utility cost breakdown for these processes.

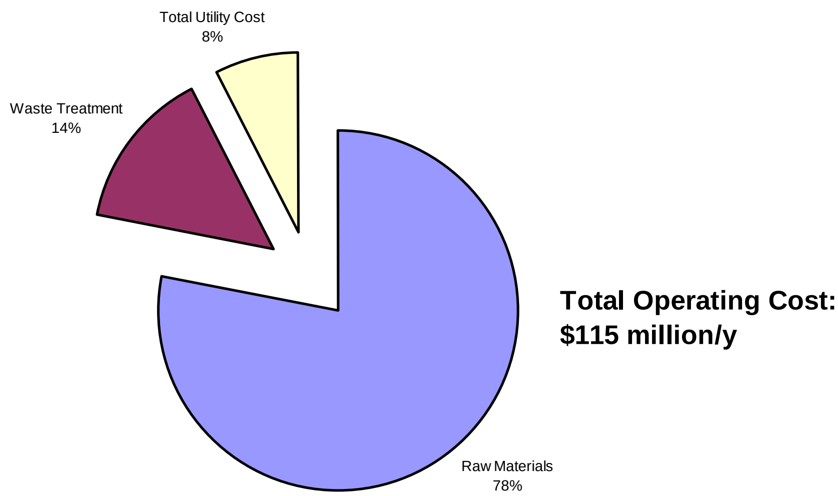


Figure 8: Yearly Operating Cost Breakdown for L-aspartic acid & L-phenylalanine

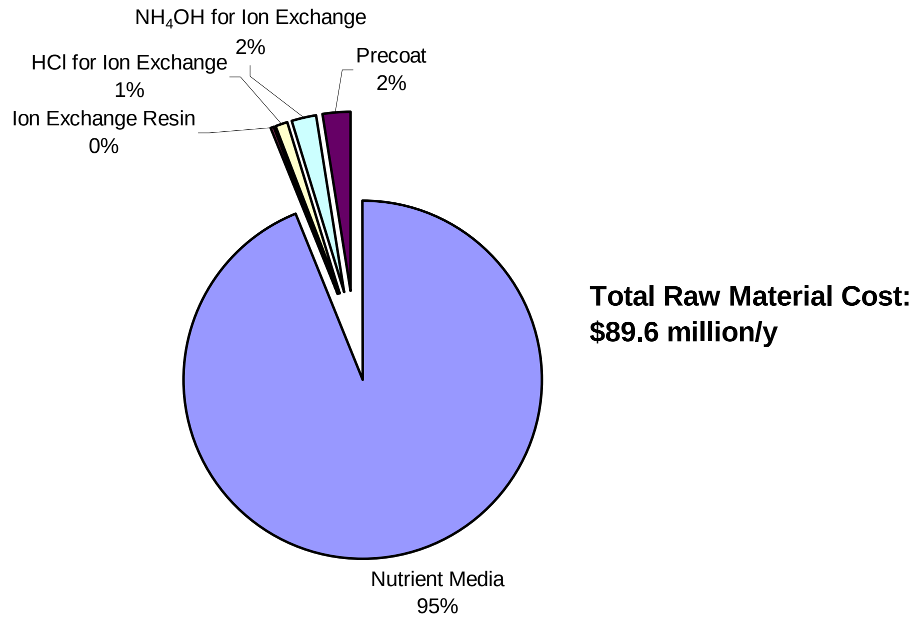


Figure 9: Raw Material Cost Breakdown for L-aspartic acid & L-phenylalanine

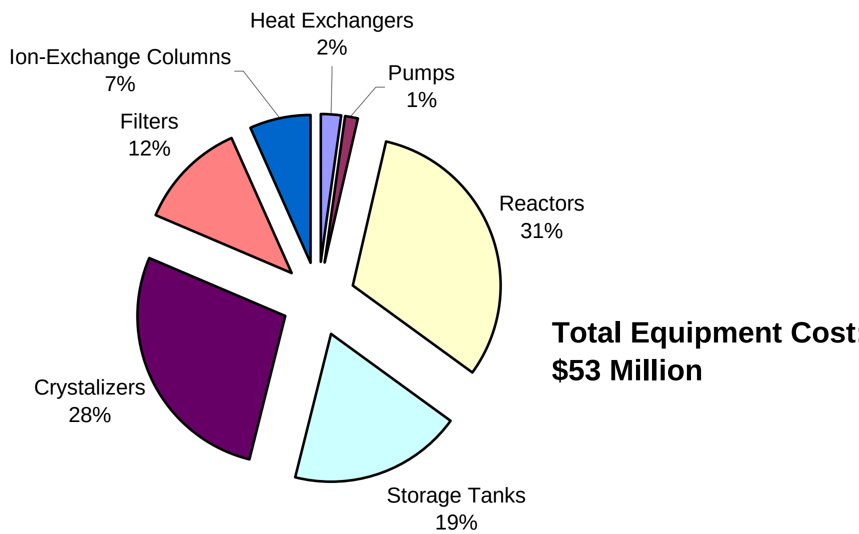


Figure 10: Total Equipment Cost Breakdown for L-aspartic acid & L-phenylalanine

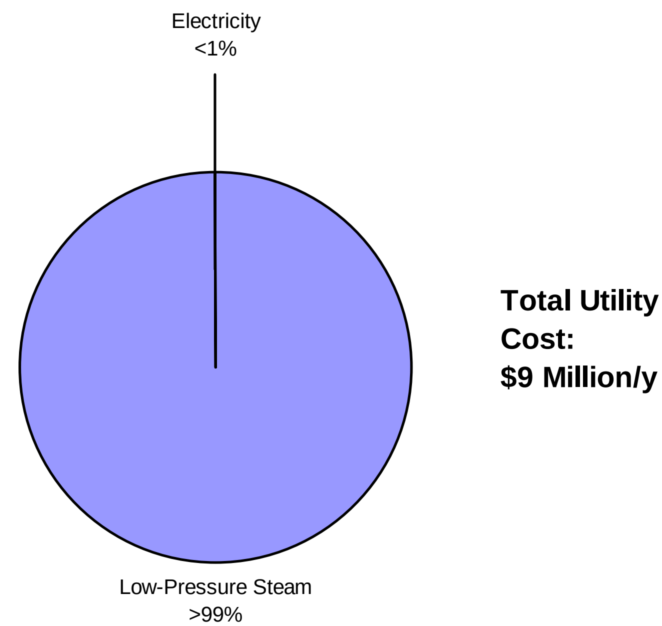


Figure 11: Total Utility Cost Breakdown for L-aspartic acid & L-phenylalanine

Conclusions & Recommendations

In conclusion, Technocats, Inc., has completed the final design for the requested amino acid facility as shown in Figure 1. Technocats, Inc., has determined equipment needed to produce L-lysine and L-leucine, as well as, additional equipment needed to produce L-phenylalanine and L-aspartic acid if the market fluctuated to do so or if a potential buyer offered an outstanding premium to produce the two. This provides Capstone Chemical Corporation with the flexibility to produce any of the four amino acids discussed above.

Another item addressed during the design process was the issue of scheduling. Scheduling was used to determine how each amino acid would "travel" through the process. A full 14-day reactor schedule was formulated to fit the 8-hour work shifts. A full 14-day schedule for the separations section was also developed and designed to fit the 8-hour work shifts. These schedules are how the batch amino acid facility will operate. The schedules are illustrated in Figures 2 and 3.

Technocats, Inc., strongly recommends the construction of the proposed batch facility. The amino acid facility will produce L-lysine, L-leucine, L-phenylalanine, and L-aspartic acid utilizing the same equipment. This provides Capstone Chemical Corporation with the flexibility to produce multiple products and shift from product to product, as the market fluctuates. The break-even and market prices for all four amino acids are summarized in Table 8.

Table 8: Amino Acid Break-Even Prices

Amino Acid	Break-even Price ($/kg)	Market Price ($/kg)***
L-lysine HCl	2.70	4.75
L-leucine	13.30	140.00

L-aspartic acid	12.00	20.00
L-phenylalanine	15.00	84.00

***all prices are quoted from *Chemical Market Reporter (March 2003)*

A detailed economic analysis including bare module costs and a 5-year Monte Carlo simulation is given in the Appendicies. The significance of this simulation is that the probability of losing money is virtually zero for the amino acids process. Detailed calculations of all equipment, cleaning times, and impeller power can also be found in the Appendicies. Finally, a reactor HAZOP, a plant plot plan, and PDMS drawings of reactors can also be found in the Appendix.

References

1. Takamatsh, T., K. Yamashita, and A. Sumi, “Kinetics of Production of L-aspartic Acid by Aspartase of Immobilized *Eschericia Coli* Cells,” *Japanese Journal of Fermentation Technology*, Vol 58, No. 2, pp.129-33, 1980.

2. Tsuchida, Takayasu and Koji Kubota, et. al. “Production of L-Phenylalanine by a Mutant of *Brevibacterium lactofermentum* 2256,” *Agricultural Biological Chemistry*, Vol. 51, No. 8, pp. 2095-2101, 1987.

3. (Rule of Thumb) http://www.glue.umd.edu/~nsw/ench485/lab9c.htm.

4. Tada, Kiyoshi, Michimasa Kishimoto, Takeshi Omasa, Yoshio Katakura, and Ken-Ichi Suga, "Constrained Optimization of L-lysine Production Based on Metabolic Flux Using a Mathematical Programming Method," *Journal of Bioscience and Bioengineering*, Vol. 91, No. 4, pp. 344-351, 2001.