AC 2009-2331: STUDENTS CREATE PROBLEMS FOR TEACHING AND LEARNING

Claire Komives, San Jose State University

Erik Fernandez, University of Virginia

Abstract
The BioEngineering Educational Materials Bank (BioEMB) is a web repository of biological applications that has been designed to enable chemical engineering students to learn to apply their chemical engineering principles to biological processes and problems. In spite of getting many offers of contributions to the website from Biochemical Engineering faculty, only very few problems were submitted except by a handful of faculty. In order to expand the contributions to the website, students in the senior Biochemical Engineering elective course were assigned the task of creating problems suitable for the BioEMB website. The problem creation was generated from information in research papers on bioprocesses. Coupled with a rubric for the problem development and some mentoring by the faculty, students have learned about process design, along with the peer review and publishing aspect of having their problems posted on the website. The project has shown that students can learn about applying material balance concepts to the scale-up of published data and information to develop a process design strategy. In turn, the problems were "beta-tested" in the undergraduate chemical engineering core course. Assessment of this project by means of surveys of the students who developed the problems, surveys of the students who solved the problems in the chemical engineering course, as well as the peer review of the problems by biochemical engineering faculty will be presented. This strategy for student learning could effectively be utilized with other application areas as a way to incorporate more interdisciplinary learning in the undergraduate curriculum.

Introduction
Since the late 1990's there has been a drive to integrate more biological applications into the undergraduate chemical engineering (ChE) curriculum. The availability of employment opportunities in the life sciences has grown steadily for ChE graduates, spurred by the expansion of bioprocessing to include both high margin fine chemicals and therapeutics as well as low margin commodities[1, 2]. In 2001, a workshop was held at the National Science Foundation to assemble a set of recommendations for embellishing the undergraduate ChE curriculum with more biology [3]. Since that time, the National Science Foundation has supported the development of educational resources for biochemical engineering education, including a set of workshops and modules organized through Tufts University[4]. NSF also sponsored workshops to discuss the modernization of ChE education [5] with a particular emphasis on the integration of biology, molecular transformation, and other frontier areas into the ChE curriculum. A significant outcome of the projects is an increased awareness among ChE faculty of the need to enrich and revitalize ChE education to address the needs of industry and the interests of students. A strong endorsement for including more biology in the ChE curriculum is the considerable number of ChE departments that have included "biological," "biochemical," or other type of bioengineering program in the department name.

The Bioengineering Educational Materials Bank (BioEMB) was conceived at an American Chemical Society meeting in 2004 during an education session that was held as part of the Biochemical Technology Division symposium [6]. The session was attended by both industrial and academic participants. The general consensus at this gathering was that a database of solved problems addressing biological applications would enable faculty to begin to incorporate bio into their courses. The database would function as a supplementary solution manual to the textbook solution manual. An NSF Course, Curriculum and Laboratory Improvement proposal was funded in January, 2007 to the authors of this paper, and the plan was to develop 100 problems with solutions for the Material and Energy Balance course.

BioEMB has a number of useful attributes for faculty. Unlike a static solution manual, the problems on BioEMB can be easily modified. Thus, mistakes in calculation, typo's and other errors can be easily fixed and reposted. Students can only access the problem statements, problem abstracts that provide a context for each problem, a pop-up dictionary of definitions to help clarify terms, and downloadable word files of the problems. The website (http://www.bioemb.net) stores the problems in a MySQL secure database and each of the faculty users obtains a unique "account" once they have been confirmed. Only upon activation of a faculty account can the solutions to the problems be accessed.

One of the reviewer concerns of the project was that faculty would not readily develop problems and submit them to the database for posting. With a few notable exceptions, this concern has turned out to be quite true. A small number of faculty provided many problems and a few others sent one or two. While many faculty said they would submit problems, only a handful have done so. With the goal of providing problems with a breadth of applications, the capabilities of the website to have the problems generated by only a few people are limited. On the other hand, students have the knowledge of basic ChE concepts, such as material and energy balances, and can be motivated to generate problems that can be posted onto the website for others to use.

The practice of student development of problems has been shown to be an effective learning strategy. Literature reports focused on the development of final exams and exam questions to help students engage in the course material and take ownership of the key concepts. Brown showed that students were more motivated to complete the course requirements when challenged with generating final exam questions [7]. Brink and coworkers gave manufacturing engineering students the assignment to create a final exam and solution as part of a freshmen course curriculum. The results of the study showed there was a correlation between the quality of student generated final exams and their final exam score [8]. The approach of having students develop problems appropriate for their current course was used in a math course as an assessment of students' higher learning abilities. [9] The author commented that the exercise was very time consuming for her (the faculty), but concluded that the extra work was a valuable investment for improving her students' learning.

As compared to developing exam problems for the course in which the students are currently enrolled, the student generation of homework problems described in this paper would be analogous to the development of a simple case study or design problem. However, the authors were not able to find any papers in the literature that described the development of either homework problems or case studies as part of a specialized elective course for the purpose of incorporating interdisciplinary curriculum into a separate, core chemical engineering course. Some aspects of the problem development are clearly relevant to the education of any student, namely, designing a simple process flowsheet from information in a research paper and performing the material balance calculations on the process. Likewise, the writing of the abstract that describes the context and relevance of the problem are also skills that are important for any student who will be called upon to explain the value of a technology to colleagues in a workplace. The aspects of the problem involving the wording of the problem or associating learning objectives with a problem are less critical to the education of the students, and these parts were not included in the grading of the problems.

Students in the upper division elective course, Introduction to Biochemical Engineering (CHE 192), including both senior and graduate ChE students, were assigned the task of developing a problem for the BioEMB website. This paper will describe the strategy of the assignment, learning outcomes as manifested by the problems developed and also the results of a survey given to the students. The student-generated problems were then assigned as extra credit problems to the undergraduates in the Material and Energy Balance (CHE 115) course for *beta testing* and the participating students were consequently surveyed about their educational experience with the posted BioEMB problems and the extra credit students-generated problems.

Methods

The problem development assignment was given to students in two consecutive years. Students were given a general grading rubric for developing their problem that is shown in Table I. (see also Appendix I for the homework assignment instructions), along with a problem and solution from the BioEMB website as an example. Likewise, students were provided with research papers that contained data for developing a process. The papers were chosen from recent literature on a variety of process types, including biotransformation processes[10], production of intracellular products[11], biofuel process[12], and other areas. The first year, as there were 30 students in the class, they were assigned to groups of two or three to develop the problem. The problem development assignment was worth 15% of the total course grade. Students were given two weeks to develop the problem.

Table I. Rubric for Problem Development Assignment

30% accuracy of the calculation
1 = more than 2 errors; 3 = one or two minor errors; 5 = no errors

20% faithfulness to the chosen paper
1 = altered substrates, 3 = same substrate and product but altered productivity (if given), 5 = process uses same substrate, product, productivity or titers presented in paper

30% difficulty of the problem
1 = less than 6 calculations required; 3 = 7-10 calculations required, 5 = 11 or more calculations required.
(calculations include appropriate (meaningful) unit conversions, molecular weight determinations, balances, process conversion calculations, productivity calculations, degree of freedom analysis, etc.)

20% presentation of the problem
1 = missing any of the following: title, abstract, problem statement, process flow diagram (does not need to have all the numerical values, just variables), solution.
3 = complete problem includes all parts but has significant grammatical errors or confusing statements
5 = clear and complete problem without grammatical errors.

The second year of the assignment, students were given the assignment on the first day of the Introduction to Biochemical Engineering course. Because there were only ten students in the class, they were given the assignment to develop a problem individually. Assuming that they would have had a course in Material and Energy Balances (MEB), and students would have had a course in biochemistry as a prerequisite to the biochemical engineering elective course, they would have already learned the technical aspects of solving the material balance of a biological problem.

Upon receipt of the problems when the students turned them in, it was necessary to review them for gross errors in process design, as well as inaccuracies in the abstracts and other flaws that would make the problem impossible for a student in the MEB course to understand and solve. About 30% of the problems were acceptable in their current form, but could be improved for clarity and other minor edits. Most of the students' problems required major revisions, so the papers were returned to the students to try again with the same rubric. The students were happy to have a chance to fix their errors and improve their chances for a good grade. In fact, about 50% of the students' papers after the first revision still required major revisions. While this might seem to indicate that the students did not try hard enough, it presented a great opportunity to work with the students on the issues that were still unclear to them.

Because it was nearing the end of the semester after three rounds of revision, the problems were given to the MEB students without further modifications. As can be seen in the survey data, there were still errors in some of the students' problems, and that caused some difficulties for the MEB students. The MEB students were offered extra credit for each of the problems solved correctly, providing motivation for them to do this assignment when they were very busy with preparation for finals in all their classes.

Results

First year outcome – SJSU (C. Komives)

Students completed the assignment after two and sometimes three revisions and then were offered extra credit to submit the problems to the BioEMB website that has a Manuscript Central link for submission and peer review of the problems. Only five of the groups elected to submit their problems to the Manuscript Central site, representing about one third of the possible problems. The problems were sent out for review to some faculty who had volunteered to review problems and some faculty who had never volunteered but were experts in the technical areas of the problems. The response was general willingness but, in the end, only two of the reviewers actually reviewed their problems. Students were subsequently unwilling to make any revisions to their problems for resubmission. As a result, the beta testing and review of the problems was not carried out and the first round of problems did not result in any postings to the BioEMB website.

First year outcome – UVA (E. Fernandez)

In Spring 2008, a similar assignment was given to a biochemical engineering class at the University of Virginia. In anticipation of expanding the BioEMB site to other chemical engineering core courses, the paper topics and assignment were broader, with four groups preparing homework problems involving thermodynamics, and twelve remaining groups developing problems that could be used in either a reaction engineering or a biochemical engineering course. A peer review step was included which provided one round of review, although the reviews were not particularly critical. As in the SJSU experience, the problems were not ready for posting, and more lead-time for revisions was suggested. Further, while a survey was not administered, a number of unsolicited positive comments about the value of the assignment appeared in the course evaluations.

Second year outcome – SJSU (C. Komives)
To facilitate having sufficient time for multiple revision cycles as well as the beta testing in the MEB course, the assignment was given on the first day of class to the CHE 192 students. Ten unique problems were created and some of these problems could be judged to be of high quality for use in a MEB course. However, the beta testing was completed only recently and additional corrections should be made to the problems prior to posting on the website. Thus, at the time of preparing this manuscript none of the new problems have been posted to the BioEMB website. It is expected that by the time of the ASEE presentation, at least some of the problems will be corrected and posted.

Learning experience for upper division biochemical engineering students
As compared with traditional homework problems, in-class group work, exams and term papers, the educational experience in developing a problem is an excellent learning opportunity for students. The problem is open ended and therefore, the Bloom's taxonomy level is 5-6 for designing the process flowsheet, evaluating the process yields, and applying the basic chemical engineering principles to a problem that does not have any fixed solution. Because of the challenge associated with developing a process design from the literature reports, students were inclined to "make up" numbers for their problems without any basis in fact, as well as to write a chemical balance for a process that may never be able to occur in reality. These were opportunities to work with the students individually to develop their processes. For example, it was instructive to encourage them to find similar published processes that they could use to help approximate expected yields, including showing them where to find the types of information necessary to complete their assignment. Likewise, it was common for the students to ignore other process constraints, such as mass transfer resistances, in developing their processes. It was not apparent to them that the oxygen enters the process as a gas (air) and is utilized in the liquid phase, thus they need to consider the mass transfer of oxygen into the aqueous media. In addition, students had to learn that they cannot draw a box on their flowsheet and identify the separated streams out of convenience. It is necessary to consider the physical properties of the chemicals being separated and ascertain the most practical separation method available for the task. The problem development provided an opportunity to work with each student individually to find data and identify misconceptions about bioprocess design, which was valuable for both the instructor and the students.

The students were surveyed anonymously at the end of the semester about the problem development assignment. There were only 10 students in the course and all of them turned in the survey. Students judged that they spent an average of 15 +/- 3 hours to develop their problems over the course of the semester. Eight of the 10 felt that 15% of the course grade was about the right amount of credit for the assignment. All ten of the students agreed that future CHE 192 students should do the problem development assignment, although only half of them felt that it should be on material and energy balances whereas the remainder of the students felt the problem could address another course of the students' choosing. Seven of the students agreed or strongly agreed that they enjoyed the problem development exercise and the remaining three somewhat agreed that it was an enjoyable experience. The idea of publishing the problem was very important or somewhat important to nine of the students, and six of the students agreed they would be willing to make additional corrections after the course was over in order to get it posted on the BioEMB website. Four of the students checked that the assignment was a significant contribution to what they learned in the course and the other six chose the option that the assignment contributed somewhat to what they learned in the course, and thus, none of the students checked that they did not learn anything from the exercise. Finally, students were given the opportunity to select the type of content they learned from the exercise. Seven students agreed that they learned more about solving a material balance than they knew previously, three learned more about process design than they knew previously and four checked that they learned a new bio application. None of the students chose the option that the assignment was routine and they did not learn anything new from it.

Learning experience for material and energy balance students

Again, students were surveyed anonymously about the learning experience they got from solving the problems developed by the biochemical engineering students. Being the first time this approach was taken, some improvements are warranted for next years attempt. One of the students commented that the problems should be proofread prior to giving them to MEB class. As they were proofread three times, this is useful information about the high quality of problems generally assigned to these students! On the other hand, now that the problems have been assigned once, errors have been identified and it will be easier to polish the problems for posting on the BioEMB website.

Twenty students completed the MEB course, twelve students turned in extra credit problems, and ten students returned the survey. It should be pointed out that only students who solved the extra credit problems turned in surveys, and therefore, the group of students completing the survey was a set of students that perceived a need to raise their grade through getting extra credit. Students completing the survey had solved an average of 75% +/- 7% of the 11 BioEMB problems that had been assigned throughout the semester from the website, so they had been exposed to material balance problems dealing with bioprocesses prior to seeing the extra credit problems that had been developed by the biochemical engineering students. The surveyed students had attempted to solve 2.3 +/- 0.3 of the extra credit problems and then turned in an average of 1.8 problems for credit. They were allowed to turn in up to three problems and would get credit for each problem turned in and completed successfully.

Questions on the survey dealt mainly with the students' analysis of the quality of the extra credit problems as compared with those posted on the website. Several of the students' solutions perfectly matched the solutions provided by the upper division students, including some calculation errors. On the other hand, one of the MEB students came twice for guidance about inconsistencies in the problems she was solving and e-mailed specific questions dealing with similar apparent errors in the problem statements and her solutions looked different than other students who solved the same problem. It was clear that several of the MEB students wanted the extra credit badly and were not inclined to work through the problem solutions carefully, thus the most direct route to their credit was to identify the upper division student who had created the problem and get some assistance from them. Because of this failure in the design of the assignment for the MEB students, some of their survey responses may have been influenced by the ease of solving a problem with a provided solution. For example, 5 of the students polled said that the extra credit problems were easier to solve than the ones on the website. It is unclear whether this is because they had already solved the ones on the website and therefore had some experience, or if the extra credit problems were easier because the solutions were provided, or if the problems were really less challenging than the ones on the website. Regarding clarity of the problem statement, five students said the extra credit problems were clearer than the ones on the website, two said the degree of clarity was about the same and three said the problems were confusing. Again, it is not directly evident that the extra credit problems are more clearly stated than the ones on the website.

Based on the results of this beta testing strategy, the path forward will be to carefully work through the problems, polish them and subject them to one additional round of beta testing prior to posting on the website.

Summary of assignment from the faculty perspective

As the assignment was given and processed during this past fall, there are some notable flaws in the learning experience given that some of the students' problems still had errors in them after three rounds of revisions. To address this problem, the presentation of the assignment should be modified to cover some of the typical mistakes that students make in developing the problems. The ones mentioned in the section on learning experience for biochemical engineering students should be included. Second, a careful evaluation of the problems to ensure there are no errors in the calculations, while very time consuming, is the necessary faculty input to make the exercise complete. There is no doubt that the amount of faculty time associated with this assignment is much greater than for standard homework problems where a correct solution is available, or even term papers, where the errors tend to be in the verbal statement of concepts. The practice at UVA of having students from the upper division course serve as peer reviewers for a first round appears to be somewhat helpful to reduce the errors.

Conclusion

Students were given the assignment to develop problems on biological applications to be posted on the BioEMB website. Students were surveyed and overall were very positive about how much they learned doing the assignment and even, for the most part, enjoyed the assignment. They agreed that future biochemical engineering students will benefit from the assignment as they did, whether they develop the problems on MEB or other chemical engineering principles. The problems were beta tested in the MEB course at the end of the semester and these students had mixed reactions with regard to the quality of the problems as compared with the other BioEMB problems they had solved throughout the semester. The amount of faculty time associated with the assignment is high, but the project will be continued in future biochemical engineering courses because of the educational value for the students.

1. Wood, A. and A. Scott, *Bioprocessing: reaping the benefits of renewable resources.* Chemical Week, 2004. **166**(5): p. 15-17.
2. Villadsen, J., *Innovative technology to meet the demands of the white biotechnology revolution of chemical production.* Chemical Engineering Science, 2007. **62**(24): p. 6957-6968.

3. *Future directions of biochemical engineering: Vision and priorities*, 2001, National Science Foundation, Bioengineering and Environmental Systems Division: Arlington, VA. p. 30.
4. *Exerpts from NSF Grant #0343135 to Tufts University.* 2003.
5. *Frontiers in Chemical Engineering Education.* 2003 [cited; Available from: http://mit.edu/che-curriculum/index.html.
6. Arnaud, C.H., *Modernizing Chem Engineering.* Chemical & Engineering News, 2007. **85**(42): p. 42.
7. Brown, I.W., *To Learn is to Teach is to Create the Final Exam.* College Teaching, 1991. **39**(4): p. 150-153.
8. Brink, J., E. Capps, and A. Sutko, *Student Exam Creation as a Learning Tool.* College Student Journal, 2004. **38**(2): p. 262-362.
9. Rash, A., *An alternative method of assessment: using student-created problems.* Primus, 1997. **7**(1): p. 89-95.
10. Barghini, P., et al., *Vanillin production using metabolically engineered Escherichia coli under non-growing conditions.* Microbial Cell Factories, 2007. **6**(13): p. 1-11.
11. Yezza, A., et al., *Production of poly-β–hydroxybutyrate (PHB) by Alcaligenes latus from maple sap.* Applied Microbiology and Biotechnology, 2007. **77**(2): p. 269-274.
12. Lau, M.W., B.E. Dale, and V. Balan, *Ethanolic fermentation of hydrolysates from ammonia fiber expansion (AFEX) treated corn stover and distillers grain without detoxification an dexternal nutrient supplementation.* Biotechnology and Bioengineering, 2008. **99**(3): p. 529-539.

Appendix I: Homework Assignment for Biochemical Engineering Students

Material Balance Problem:

The goal of this assignment is to generate an original biochemical engineering problem to be PUBLISHED with your name as author on the BioEMB website (http://www.bioemb.net). The website is a source of solved problems for faculty in chemical engineering departments all over the world to incorporate bio-based problems in their undergraduate chemical engineering courses.

What do you need to do:

1. Choose a paper from the ones identified (list on course website) or find a different paper of your choice but get it approved by professor. The papers include research on the production of some protein or chemical from a biocatalytic process.
2. Read the paper and identify key information such as production rates, amounts of substrates, type of organism, process characteristics, etc.
3. Identify which species can be balanced in the process (at least carbon, possibly nitrogen and oxygen).
4. Develop the process flow sheet and show the input and exit streams. Standard rules for process flow diagrams apply - for reference on this, check Felder & Rousseau (Elementary Principles of Chemical Processes).
5. Generate a problem statement that provides enough information to solve the problem. Try yourself to solve it to be sure the balance is correct. If you are producing a protein, look up the amino acid composition and identify the stoichiometry of the protein as $CH_xO_yN_z$. The problem should be challenging for junior level chemical engineering taking the material and energy balance course. Note that students in this course have learned about fractional conversion (f),

f = (moles of a exiting reactor - moles of a entering reactor)/moles of a entering reactor

but they have not learned about kinetics in the reactor. If you need to relate the concentration of the species exiting the reactor to the concentration entering, you should provide the relationship for them as they won't know how to relate it themselves. Likewise, they have not learned about mass transfer relationships, so those must also be provided if it is essential to the calculation.

Turn in a type-written problem together with a printed copy of your paper. The flow diagram should not be an image file but should be drawn in word with the drawing tools. The problem will be graded according to the following rubric: (See Table I in the main text).

Appendix II: Example Problem Developed by Student

Exercise: Enzymatic Catalysis of Glycolonitrile to Ammonium Glycolate Using *E. coli* Expressing a Recombinant Nitrilase.

References:

1) Wu, Shijun, Fogiel, Arthur J., Petrillo, Kelly L., Jackson, Raymond E., Parker, Kimberley N., & DiCosimo, Robert, et al. (2007) Protein Engineering of Nitrilase for Chemoenzymatic Production of Glycolic Acid. *Biotechnology and Bioengineering (99)* 3, 717-720.

2) Panova, Anna, Mersinger, Lawrence J., Liu, Qiang, Foo, Thomas, Roe, D. Christopher, Spillian, William L., et al. (2007). *Chemoenzymatic Synthesis of Glycolic Acid. Advanced Synthesis & Catalysis, (349)* 1462-1474.

3) Hann, Eugenia C., Sigmund, Amy E., Hennessey, Susan M., Gavagan, John E., Short, David R., & Ben-Bassat, Arie, et al. (2002) Optimization of an Immobilized-Cell Biocatalyst for Production of 4-Cyanopentanoic Acid. *Organic Process Research & Development (6)* 4, 492.

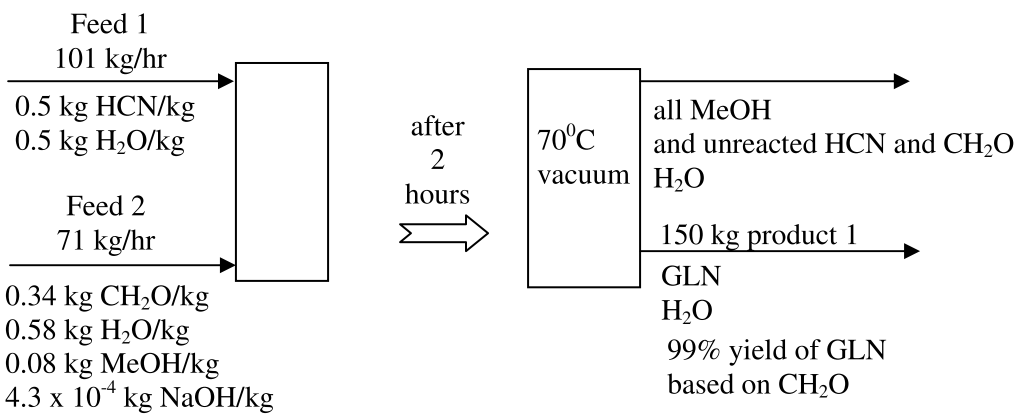
Author: Brian Y. Wong

Abstract: Ammonium glycolate can be used for commercial production of glycolic acid, which is widely used in industry for many products, from skin care ingredients to flavoring and dying agents. Ammonium glycolate can be produced as a catalytic process using nitrilase extracted from *Acidovorax facilis* 72W and glycolonitrile (GLN). More recent studies have shown that using an engineered nitrilase enzyme that was cloned and expressed in Escherichia coli resulted in increase catalyst activity and product yield. Based upon the strain type of *E. coli* used in the enzymatic production of ammonium glycolate, various enzyme expression levels and catalyst productivities were observed (Panova, et al., 2007 & Wu, et al. 2007). This problem explores a process for ammonium glycolate production using encapsulated *E. coli* cells engineered for the overexpression of nitrilase.

Problem Statement: Roland is a new chemical engineer at EZ Co. and is assigned to the ammonium glycolate synthesis process. The first step in the process is the synthesis of GLN (C_2H_3NO) from formaldehyde (CH_2O) and hydrogen cyanide (HCN). Formaldehyde and hydrogen cyanide are both fed as aqueous solutions into the reactor in separate streams as shown on the flowsheet. Methanol, unreacted HCN and CH_2O and water are removed by vacuum after a two hour period. GLN solution is fed at 15kg/hr into a 22.5 L packed bed reactor with E. coli immobilized within packed beads. The enzymatic hydrolysis of GLN yields ammonium glycolate ($C_2H_7NO_3$) at 100% conversion. (Hann, et al. 2002). The balanced stoichiometric equation for the hydrolysis of GLN is $C_2H_3NO + 2H_2O \rightarrow C_2H_7NO_3$. For each aqueous solution, assume that the volume change of adding H_2O into the reactor is negligible and the process is continuous and at steady-state.

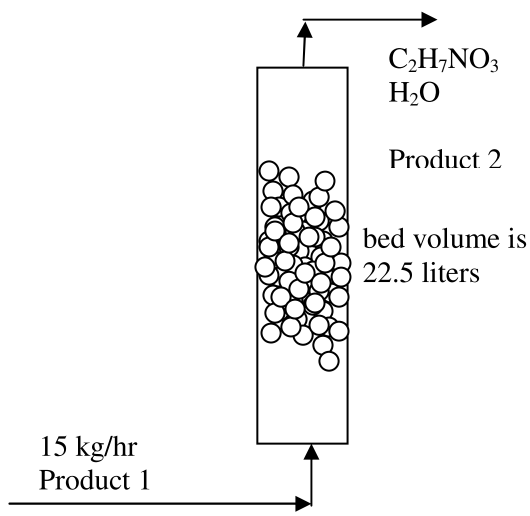
A) For his first task, Roland was asked by his supervisor to calculate the weights of GLN and water in product 1, which is to be the feed stream to the bioreactor, as well as the amounts of HCN and methanol that are removed in the vacuum chamber.
B) Roland's next task is to compare the E. coli strains that can be potentially used as catalyst. The first strain of E. coli has no mutation and a cell-specific activity of 490 GLN U/g dcw where the unit [U] equates to 1 µmole conversion of GLN per minute. The unit [dcw] is the dry cell weight of E. coli used as catalyst. The second strain is mutation F168V and has a cell-specific acitivity of 1,992 GLN U/g dcw. Determine how much (dcw) of each strain would be required for the above process flow. Assuming both strains cost the same by weight, which strain should Roland use?

C) Roland is asked to calculate the mole of ammonium glycolate and water leaving the bioreactor.



Step 1: Formation of GLN

Step 2: Concentration of GLN



Step 3: Conversion to Ammonium Glycolate

<u>Solution:</u>

A) We consider the conversion of formaldehyde to GLN.

$$\frac{0.34kg\_CH_2O}{kg\_solution} * \frac{71kg\_solution}{hr} * 2hr = 48.28kg\_CH_2O$$

$$48.28kg\_CH_2O * \frac{57.05g/mol\_GLN}{30.03g/mol\_CH_2O} * 0.99yield = 90.80kg\_GLN$$

The amount of water in Product 1 is then the difference between the mass of GLN and total mass.

$$150kg\_total - 90.80kg = 59.20kg\_H_2O$$

Methanol does not react and the total amount removed.

$$0.08kg\_MeOH * \frac{71kg}{hr} * 2hr = 11.36kg\_MeOH$$

To calculate the amount of HCN removed, we must calculate the residual HCN after conversion to GLN. All residual HCN is removed by the vacuum. We know that formaldehyde is the limiting reagent.

$$Consumed\_HCN$$

$$48.28kg\_CH_2O * 0.99 reacted * \frac{27.02 g/mol\_HCN}{30.03 g/mol\_CH_2O} = 43.01kg\_HCN$$

$$Initial\_HCN$$

$$\frac{0.5kg\_HCN}{kg\_solution} * \frac{101kg}{hr} * 2hr = 101kg\_HCN$$

$$Residual\_HCN$$

$$101kg - 43.01kg = 57.99kg\_HCN$$

B) We know 150 kg of Product 1 is fed into the reactor. Product 1 is being fed at 15 kg/hr.

$$150kg\_Product1 * \frac{1hr}{15kg} = 10hr$$

The rate of GLN fed into the reactor is then calculated using mass from Part A).

$$\frac{90.80kg\_GLN}{10hr} = \frac{9.08kg\_GLN}{hr}$$

For the non-mutated strain the amount of catalyst required is calculated.

$$\frac{9.08 * 10^3 g\_GLN}{hr} * \frac{1mol}{57.05g} \div \left[\frac{\frac{490\mu mol}{\min} * \frac{60\min}{hr} * \frac{1.0e-6mol}{1\mu mol}}{g\_dcw}\right] = 5{,}413g\_dcw$$

For the second strain E. coli F168V the amount of catalyst required is compared to the first.

$$\frac{9.08 * 10^3 g\_GLN}{hr} * \frac{1mol}{57.05g} \div \left[\frac{\frac{1992\mu mol}{\min} * \frac{60\min}{hr} * \frac{1.0e-6mol}{1\mu mol}}{g\_dcw}\right] = 1{,}332g\_dcw$$

Roland should use E. coli F168V since the amount of catalyst required for the same weight of GLN is roughly 4 times less than the E. coli with no mutation.

C) The stoichiometric equation for the hydrolysis of GLN to ammonium glycolate is:

$$C_2H_3NO + 2H_2O \rightarrow C_2H_7NO_3$$

The molar flow of ammonium glycolate in the product stream, assuming 100% conversion of GLN is:

$$\frac{9080g\_GLN}{hr} * \frac{1mol}{57.05g} * \frac{1mol\_C_2H_7NO_3}{1mol\_C_2H_3NO} = \frac{159.2mol\_C_2H_7NO_3}{hr}$$

The mols of water entering the bioreactor is then:

$$5.92\frac{kg\_H_2O}{hr} \cdot \frac{kmol\_H_2O}{18\_kg\_H_2O} \cdot \frac{1000mol}{kmol} = \frac{329mol\_H_2O}{hr}$$

The mols of water leaving the bioreactor are then:

$$\frac{329mol\_H_2O}{hr} - \left[\frac{2\_mol\_H_2O}{mol\_C_2H_7NO_3} \cdot \frac{159.2mol\_C_2H_7NO_3}{hr}\right] = \frac{10\_mol\_H_2O}{hr}$$