National Student Design Competition 2012

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS
Three Park Avenue, New York, New York 10016

If there are any questions about the design problem, Student Chapter Advisors and design course instructors are asked to contact:

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Please read the rules **before**, **during** and **after** preparing and submitting the solution to AIChE.

NOTICE: THE PAGE LIMIT FOR THE REPORT IS 125 NUMBERED PAGES!

AMERICAN INSTITUTE OF CHEMICAL ENGINEERS
345 East 47th Street, New York, New York 10017-2395

AIChE National Student Design Competition 2012

PRODUCTION OF NON-ALCOHOLIC BEER USING A REVERSE OSMOSIS MEMBRANE PROCESS

DEADLINE FOR MAILING

Solutions must be postmarked no later than Midnight, June 2, 2012.

RULES OF THE CONTEST

Solutions will be graded on:

- sound economic analysis, leading to an economic optimum
- correctness of results.
- soundness of conclusions.
- ingenuity and logic.
- accuracy of computations.
- form of presentation.

The statement of the problem contains all the pertinent data except for those available in handbooks and literature references. The Web will be a valuable resource. The use of textbooks, handbooks, journal articles, and lecture notes is permitted. Reference 3 will be very helpful to determine the composition of the many numerous flavor compounds in beer. Students may use any available commercial or library computer programs in preparing their solutions. If students use commercial or library computer programs or other solution aids, they should state it in their reports and include proper references and documentation. The problem can be solved without the use of sophisticated computer programs. Judging is based on the overall solutions, not on skills in manipulating computer programs.

The 2012 National Student Design Competition is designed to be solved either by an individual chemical engineering student working entirely alone, or a group of no more than three students working together. Solutions will be judged in two categories: individual and team.

There are other approaches to using the problem, and it is expected that some Advisors will use the problem as classroom material. The following confidentiality rules therefore apply:

Students submitting solutions:

The problem may not be discussed with anyone (student, faculty, or others, including contacts with vendors and experts not at the university, in or out of class) before or during the period allowed for solutions. Discussion with faculty and students at that college or university is permitted only after complete final reports have been submitted to the Chapter Advisor.

Students not submitting solutions:

Discussion with faculty and with other students at that college or university who are not participating in the contest is permitted. However, if any individual or team at that college or university is solving the problem under competition rules, rigorous and foolproof procedures must be established to prevent any communication between those competing under contest rules and those students using the problem otherwise.

All students:

The problem may not be discussed with students or faculty from other colleges or universities, or with individuals in the same institution who are still working on the problem for the contest, until after June 1, 2012. This is particularly important in cases where neighboring institutions may be using different schedules.

RULES FOR SUBMITTING SOLUTIONS

(Failure to comply will result in solutions being returned to the appropriate Faculty Advisor for revision. Revised submissions must meet the original deadline.)

ELIGIBILITY

- ONLY AIChE NATIONAL ENROLLED. UNDERGRADUATE STUDENT MEMBERS MAY SUBMIT A SOLUTION. Non-member entries will not be considered.
- Entries may be submitted either by individuals or by teams of no more than three students. Each team member must meet all eligibility requirements.
- Each Faculty Advisor should select the best solution or solutions, not to exceed two from each category (individual and team), from his or her chapter.

TIMELINE FOR COMPLETING THE SOLUTION

- Students are allowed no more than thirty days to complete the problem. This period may be selected at the discretion of the individual advisor, but in order to be eligible for an award a solution must be post marked no later than midnight, June 1, 2012.
- THE FINISHED REPORT SHOULD BE SUBMITIED TO THE FACULTY ADVISOR WITIITN THE 30-DAY PERIOD.

REPORT FORMAT

- The report must be suitable for reproduction, that is, typewritten or computer-generated. Tables may be written in ink. Supporting calculations and other appendix material may be in pencil.
- The report should not contain any reference to the student's names or institution. Graph paper naming the institution should be avoided.
- THE REPORT MUST NOT EXCEED 125, NUMBERED PAGES. ANY REPORT EXCEEDING 125 PAGES AND/OR WITHOUT ALL PAGES NUMBERED IN THE LOWER RIGHTHAND CORNER WILL BE RETURNED TO THE FACULTY ADVISOR.

SENDING THE SOLUTION TO AIChE

- Two copies of each of the solution(s) must be sent to the below address. Original manuscript(s) must remain in the possession of the Student Chapter Advisor, or Faculty Advisor, sponsoring the student(s).
- The content of the solutions submitted to the Faculty Advisor and the AIChE office must be the same.
- Each copy must be accompanied by the enclosed ENTRY FORM giving each contestant's name, AIChE membership number, college or university, Faculty Advisor name, address, home address, home telephone number, and student chapter, lightly attached to the report. This form is used by AIChE for identification.
- DEADLINE: Entries must be postmarked no later than midnight, June 1, 2012.
- As soon as the winners have been notified, original manuscripts must be forwarded to the AIChE office.

SEND TO:

Awards Administrator
American Institute of Chemical Engineers
3 Park Avenue
New York, New York 10016
Ph: 212-705-7478

DEADLINE: JUNE 1, 2012

AIChE 2012 National Student Design Competition: Production of Non-Alcoholic Beer Using Reverse Osmosis Membranes

CONTEST **PROBLEM** STATEMENT OUTLINE

NOTE: Every single item identified here in the Table of Contents must have its starting page number assigned to it in the Table of Contents.

PRODUCTION OF NON-ALCOHOLIC BEER USING

A REVERSE OSMOSIS MEMBRANE PROCESS

INTRODUCTION & PROBLEM STATEMENT

PRO-D-ZINE INC.
1996 Hops & Brew Way
Gulfcoast, TX 70011
October 3, 2012

TO: D. G. Designer, T. B. Engineer, W. W. Optimize

FROM: P. D. Owner

SUBJECT: NON-ALCOHOLIC BEER FOR A VALUED CLIENT

Some of you have heard "war stories" about the work we did back in 1996 to design a distillation process for producing non-alcoholic (NA) beer. That effort was very successful because the process was implemented at several breweries in the US and the rest of the World (REW).

We now have another opportunity to design a plant(s) to produce NA beer. Our client is interested in evaluating the economics of producing NA beer in Alabama, Georgia, California, Florida and Texas. They are targeting breweries producing 60,000 barrels/year (BPY) but have excess capacity, up to an additional 30,000 BPY (with essentially no additional capital expenditures).

Their primary consideration is to determine the minimum capacity of NA beer – above 60,000 BPY of alcoholic beer – which will return at least 15% IRR on invested capital. They would love to know the required capacities of NA beer would provide IRR's of 20%, 25%, 30% and 35%.

Process Technology

It is well known that the current preferred technology for producing NA beer from alcoholic beer is membrane reverse osmosis (RO). The following URL's give information about RO production of NA beer. There is much more information about this matter on the Web. All Web based information is allowed and its use is encouraged.

+ http://www.desline.com/articoli/7861.pdf
+ http://www.alfalaval.com/solution-finder/products/membrane-filtration-systems/Documents/PCM00070EN_LOWRES_beer%20deal.pdf

A Process Flow Schematic (PFS) from the Alfa-Laval document (the 2nd URL above) is given below. The explanation of the process operation from that document is given below.

Operating principles

The membranes separate the feed beer into two streams. The permeate stream (consisting of water and alcohol) passes through the membranes, whereas the retentate stream, consisting of concentrated proteins, colours and flavours, does not, and can therefore be led back to the beer tank.

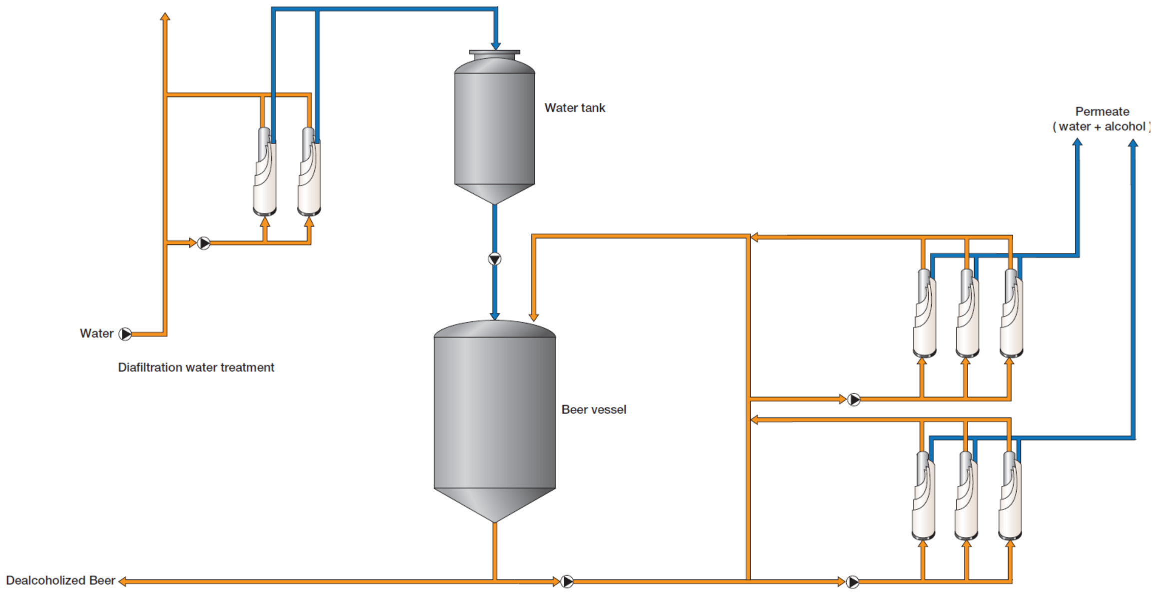

Fig. 1 Flow chart of the beer dealcoholization system

The original beer from the beer tank is pumped to the dealcoholization unit. Two feed pumps then bring the pressure of the beer up to 30 bar (435.1 psi). At this point, the beer is introduced into the first loop where the beer is circulated over the membranes in loop 1 by a pump. The retentate from the first loop continues to the second loop and is recirculated over the membranes in loop 2.

The retentate from loop 2 is returned to the beer tank via a pressure release valve. The permeate (i.e. the water + alcohol that have passed through the membranes) from all the loops is collected and led to a drain or stored in tanks with a view to recovering the alcohol.

The beer is made to flow parallel to the membrane surface, which keeps the membranes clean (cross-flow). Due to the static pressure of 30–35 bar (435.1 - 507.6 psi) on the membranes, the small molecules, such as water and alcohol, are pressed through the membranes, whereas the larger molecules, such as flavours, colours and protein, are unable to pass. These compounds therefore remain in the retentate.

Pre-concentration – step 1:

This step reduces the volume of the feed beer. After passing through the membrane modules, the feed beer is recycled over the batch tank. The permeate is removed, while the retentate goes back into the beer tank until the desired reduction in volume is achieved.

Diafiltration – step 2:

This step involves washing out the alcohol using diafiltration. It is similar in principle to the pre-concentration step, but diafiltration water is now added. The volume used is the same as that of the permeate leaving the installation, thus keeping the level in the beer tank constant. The diafiltration step reduces the alcohol content to the desired value for the final low-alcohol beer.

Alcohol adjustment – step 3:

After diafiltration, the beer can be adjusted still further by adding water into the batch tank in order to achieve the desired final alcohol content and to fine-tune the taste. The amount of water added is normally the same as the amount of permeate in step 1.

Post treatment – step 4:

The dealcoholized beer can be given its special characteristics by adjusting CO2 levels or by using hop extract or other flavour enhancers.

A standard system:

This standardized spiral membrane filtration system is a plugin unit that is ideal for batch operation. It is designed as a self-contained modular system mounted on frames equipped with a Cleaning-in-Place (CIP) tank and easily exchangeable spiral membranes. The permanent fixtures, such as piping, pumps, strainers, valves and fittings, as well as the control panel, are all manufactured by Alfa Laval. This is a significant advantage in terms of service and spare parts inventory. All piping and equipment in contact with the product and/or CIP liquids are of high-hygiene design, and steel parts are made of AISI 316L stainless steel or an equivalent acid-proof stainless steel material. The spiral membranes are designed for excellent hygiene and comply with the relevant food and dairy hygiene standards.

Waste:

The permeate streams are weak aqueous alcohol solutions. Any municipal waste treatment system would receive these streams for a price. Hopefully, there is a better, more economical "home" for this stream than municipal waste treatment.

Economics Considerations

NA beer has a marked economic advantage over alcoholic beer in that is free of federal taxes and likely free of state taxes. The tax consequences must be considered carefully and properly in any economic analysis.

The opportunities for implementing the RO dealcoholization process lie primarily where excess production capacity above 60,000 BPY is already installed. Thus, the client expects minimal capital expenditure required to increase capacity to 90,000 BPY, for any potential customer.

A careful analysis must be done to determine if additional operational labor is normally required as capacity is increased above 60,000 BPY in the typical brewery.

The difiltration water must be sufficiently pure to become a component of NA beer. This item must be costed appropriately.

Research Program

The process must be demonstrated on a laboratory scale. Consequently, a laboratory protocol must be a key part of the final project definition report. It must include:

1. A Process Flow Schematic of the laboratory setup.
2. A detailed list of all required equipment.
   NOTE: Illustration and photos from Google Images (http://www.schiercompany.com/Pumps.html could be quite helpful to increase reader comprehension for this report section.
3. A detailed laboratory operating procedure, including all the appropriate mass and volumetric balances. An itemized step-by-step procedure is recommended.
4. Testing procedures must be included.
5. Assume a well-equipped University (U. of AR has one) laboratory is available for the research program.

Thomsen, Sanitary Pump

6. Laboratory scale membranes are not readily available. A potential source of small spiral wound units

is Sherrie McCormick at GE Power & Water, (760) 598-1800, ext. 106. Information about flat sheet test units can be found at
http://www.sterlitech.com/bench-scale-equipment/cross-and-tangential-flow-test-cells.html.

Full Scale Design Package

The objective of this study is to provide a "Schedule A" package for the full scale plant design. The Schedule A package is defined on the Process Engineering Associates Web site.
http://www.processengr.com/process_engineering_services.html
"The Schedule A or Basic Engineering Design package refers to a completed process design package that includes all the necessary information required by an Engineering/Construction firm or Detail Engineering firm to perform the detail engineering of the plant".

This Schedule A package must include all documentation for

1. Heat and mass balance for the process,
2. A complete, properly titled Process Flow Diagram which includes:
   A. Every single item of process equipment,
   B. Every process line, each numbered,
   C. All inlet and exit streams clearly identified
   D. An attached Stream Attributes Table, which included all process streams.
3. A Equipment Summary, including process specifications and equipment cost.
4. An Operating Cost Summary and
5. A complete economic analysis, based on discounted cash flows.

The Table of Contents for the report, given below, is designed to include all the components of a Schedule A package.

FINAL REPORT FORMAT

NOTES:

1. FOR CONSISTENCY, CLARITY AND UNDERSTANDABILITY, ALL OF THE REPORT MUST BE DONE IN ENGLISH UNITS!!!!!!!!!
2. These formatting requirements are mandatory (non-complying reports will not be considered)
   A. Font: 12 point Times New Roman,
   B. Single spaced,
   C. Each paragraph indented,
   D. No spaces between paragraphs
3. Every page must be numbered in the bottom right-hand corner. Section page numbers must be included in the Table of Contents.
4. **The report must not exceed 125 numbered pages.**

Table of Contents

Title Page.

Table of Contents – The report Table of Contents must include the major headings exactly as listed below.

Executive Summary - Two (2) page (maximum) condensation of the report.

Introduction - Orient the client to the assigned task.

Summary - Summarize the results of the analysis and summarize the conclusions and recommendations.

Briefly tell what options were considered and the advantages/disadvantages of each. Bottom-line Economics (e.g., capital, operating costs and economic benefits) must be included.

Conclusions - Interpret your results. List your conclusions in decreasing order of significance.

Recommendations - Emphasize business opportunity and potential process improvements. Address product quality.

Project Premises - Itemize all pertinent process and economic premises, including (1) the overall project schedule, battery limits etc., (2) feed and product specs, (3) costs of raw materials, utilities etc., (4) selling prices of all products, (5) economic parameters: including depreciation schedule, taxes, project life etc., (6) environmental requirements, (7) processing limitations, (8) existing brewery operation, (9) extraordinary costs, (10) labor cost, (11) product quality considerations.

Process Flow Diagram (PFD) - Include all items of process equipment; include and number all process streams; indicate all utilities needed per individual equipment.

Stream Attributes - For each and every stream on the PFD, include on the PFD or on a separate page a Tabulation of Stream Attributes (SA's), including Stream Number, Mass Flow of Each Component, Total Mass Flow, Temperature, Pressure and Volumetric Flow Rate (GPM for liquids &CFM for gases). Proper SA's (lb/hr of each component, T, P, etc.) from a process simulator will suffice.

Process Description - Include process conditions, equipment type and size and how the process equipment is integrated to achieve process objectives. Explain the purpose of each process equipment item.

Safety and Environmental - Note and explain any special considerations. Explain and document how emission limits were achieved.

Utility Summary - Itemize each utility by user. Give yearly cost for each user and total yearly costs.

Operating Cost Summary - Itemize using the categories given in Figure 6-8, p. 261[1].

Equipment Information Summary - Itemize operating conditions and sizes of process equipment for each and every item of process equipment and include the purchase cost of each equipment item.

Capital Estimate - Itemize process equipment costs and itemize the overall estimate per The Lang Factor Technique, p. 191 [2].

Economic Analysis - Include a discussion of the economic methods and analysis. Include appropriate cash flow analysis tables. Include any graphical representations such as Required Plant Capacity vs. IRR. The cash flow analysis must be presented in tabular form using the Worksheet given in Table 2, p. 306, 4th Ed. Peters & Timmerhaus. This table is presented as the last page of this document.

Innovation and Optimization - Explain and document what was done to drive the process Towards the economic optimum.

Engineering Calculations- Include all pertinent hand calculations. Sample calculations will not suffice; all pertinent calculations must be succinctly included and documented.

Computer Programs - Include input and output files, an explanation of the model(s) used and nomenclature.

Computer Process Simulation - Include input and output files and a simulator flow chart for one set of documented process conditions for any process simulation using standard programs such as ASPEN, HYSIM OR PRO-II. NOTE: THERE MUST BE A ONE-TO-ONE CORRESPONDENCE BETWEEN STREAM NUMBERS IN THE PROCESS SIMULATION AND STREAM NUMBERS ON THE PROCESS FLOW DIAGRAM.

Research Program – It must be included as the last section of the report, as indicated above.

REFERENCES

NOTE:

1. Peters, M.S., K.D. Timmerhaus and R. E. West, Plant Design and Economics for Chemical Engineers, 5th Ed., McGraw-Hill, New Youk, 2003.

2. Turton, R., R. C. Baille, W. B. Whiting and J. A. Shelwitz, "Analysis, Synthesis, and Design of Chemical Processes" Prentice Hall, Upper Saddle River, NJ, 2009.

3. Engan, S. "Beer Composition: Volatile Substances," Chapter 3 from FOOD SCIENCE AND TECHNOLOGY, A SERIES OF MONOGRAPHS, Vol. 2, Brewing Science, Academic Press, 1981.

Special Help

This problem is concerned with NA beer and with membrane separations. To assist the participants in understanding the concepts of these technologies, the

(1) problem statements and
(2) winning solutions to two previous Contest Problems are available on the AIChE WEB site as follows:

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The problems are identified by title below:

1. The 1996 problem, titled "Production of non-alcoholic beer"

http://aice.vo.llnwd.net/o33/docs/StudentsDesignContent-1996-2001/1996DesignContestProblem.pdf

http://aice.vo.llnwd.net/o33/docs/StudentsDesignContent-1996-2001/1996DesignContestSolution.pdf

2. The 2001 problem, titled, "Economic Recovery of Edible Protein from Cheese Whey by Ultrafiltration".

http://aice.vo.llnwd.net/o33/docs/StudentsDesignContent-1996-2001/2001DesignContestProblem.pdf

http://aice.vo.llnwd.net/o33/docs/StudentsDesignContent-1996-2001/2001DesignContestSolution.pdf

TABLE 2

Work sheet for presenting discounted-cash flow, present-value, and net-present-worth determinations

Project Title: ______________________

Notes: 1. Dollar values can be in thousands of dollars and rounded to the nearest $1,000.
2. For lines 11 and 14, company policies will dictate which tax rate, interest, and discount factors to use.
3. The estimated service life for this example is taken as 5 years.
4. For lines 5, 6, and 7, see Table 27 of Chapter 6 for estimating information and basis.

Line	Item Numbers in ( ) designate line	Year 1986 0	1987 1st	1988 2nd	1989 3rd	1990 4th	1991 5th	End-of-life working capital and salvage value
1.	Fixed-capital investment							
2.	Working capital							
3.	Total capital investment (1 + 2)							
4.	Annual income (sales)							
5.	Annual manufacturing cost							
	(a) Raw materials							
	(b) Labor							
	(c) Utilities							
	(d) Maintenance and repairs							
	(e) Operating supplies							
	(f) Laboratory charges							
	(g) Patents and royalties							
	(h) Local taxes and insurance							
	(i) Plant overhead							
	(j) Other (explain in Notes)							
5-T.	Total of line 5							
6.	**Annual general expenses**							
	(a) Administrative							
	(b) Distribution and selling							
	(c) Research and development							
	(d) Interest							
	(e) Other (explain in Notes)							
6-T.	**Total of line 6**							
7.	**Total product cost (5-T + 6-T)**							
8.	**Annual operating income (4 − 7)**							
9.	**Annual depreciation**							
10.	**Income before tax (8 − 9)**							
11.	**Income after 34% tax (0.66 × 10)**							
12.	**Annual cash income (9 + 11)**							
13.	**Annual cash flow (3 + 12)**							(see heading above)
14.	Discount factors for 15% interest							
	(a) See footnote †	1.000	0.929	0.799	0.688	0.592	0.510	0.472
	(b) See footnote ‡	1.000	0.933	0.812	0.706	0.614	0.534	0.947
	(c) See footnote §	1.000	0.861	0.741	0.638	0.549	0.472	0.472
	(d) See footnote ¶	1.000	0.870	0.756	0.658	0.572	0.497	0.497
15.	Annual present value (13 × 14)							

16. TOTAL present value of annual cash flows (sum of line 15 *not* including 0 year) = ________ in dollars or thousands of dollars

17. Net present worth = total present value of annual cash flows − total capital investment = line 16 − line 3 = ________ in dollars or thousands of dollars

† Continuous uniform cash flow and continuous nominal interest (r) of 15%.
‡ Continuous uniform cash flow and finite effective interest (i) of 15%.
§ Finite (year-end) cash flow and continuous nominal interest (r) of 15%.
¶ Finite (year-end) cash flow and finite effective interest (i) of 15%.