AIChE®

2003
National Student Design Competition

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 on the following pages carefully before submitting a solution to AIChE.

AIChE National Student Design Competition 2003

RULES OF THE CONTEST

Solutions will be graded on (a) substantial correctness of results and soundness of conclusions, (b) ingenuity and logic employed, (c) accuracy of computations, and (d) form of presentation. Accuracy of computations is intended to mean primarily freedom from mistakes; extreme precision is not necessary.

It is to be assumed that the statement of the problem contains all the pertinent data for those available in handbooks and literature references. The use of textbooks, handbooks, journal articles, and lecture notes is permitted.

Students may use any available commercial or library computer programs in preparing their solutions. Students are warned, however, that physical property data built into such programs may differ from data given in the problem statement. In such cases, as with data from other literature sources, values given in the problem statement are most applicable. Students using commercial or library computer programs or other solution aids should so state in their reports and include proper references and documentation. Judging, however, will be based on the overall suitability of the solutions, not on skills in manipulating computer programs.

The 2003 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. Solution will be judged in two categories: individual and team. There are, however, other academically sound 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:

1. For individual students or teams whose solutions may be considered for the contest:
The problem may not be discussed with anyone (students, faculty, or others, 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.

2. For students whose solutions are not intended for the contest:
Discussion with faculty and with other students at that college or university who are not participating in the contest is permitted.

3. For 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 4, 2003. This is particularly important in cases where neighboring institutions may be using different schedules.

Submission of a solution for the competition implies strict adherence to the following conditions:

(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 STUDENT MEMBERS MAY SUBMIT A SOLUTION. Non-member entries will not be considered. If you would like to become a National Student Member, we must receive your membership application and check when you submit your solution, if not before. Application forms can be downloaded at: https://www.aiche-mart.org/memberapps/student.asp

◊ 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 and send these by registered mail, as per the below instructions, to the Institute.

TIMELINE FOR COMPLETING THE SOLUTION

◊ A period of no more than thirty days is allowed for completion of the solution. 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 postmarked no later than midnight, June 4, 2003.

◊ THE FINISHED REPORT SHOULD BE SUBMITTED TO THE FACULTY ADVISOR WITHIN THE 30-DAY PERIOD.

REPORT FORMAT

◊ The body of 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 solution itself must bear no reference to the students' names or institution by which it might be identified. In this connection, graph paper bearing the name of the institution should not be used.

SENDING THE SOLUTION TO AIChE

◊ Two copies of each of the solution(s) must be sent to the address below; original manuscript(s) must remain in the possession of the Student Chapter Advisor, or Faculty Advisor, sponsoring the student(s)

◊ There should not be any variation in form of content between the solution submitted to the Faculty Advisor and that sent to the AIChE office.

◊ 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. The executive director of the Institute will retain this form for identification.

◊ DEADLINE: Entries must be postmarked no later than midnight, June 4, 2003.

As soon as the winners have been notified, original manuscripts must be forwarded to the office of the executive director as soon as possible.

SEND TO:
Awards Administrator
American Institute of Chemical Engineers
3 Park Avenue
New York, New York 10016-5991

DEADLINE: JUNE 4, 2003

Recycling Nitric Acid from a Radioactive Liquid Waste Stream

1.0 Introduction and Scope

Nitric acid is used in a processing facility as the primary solvent in the recovery of radioactive materials from residues during stabilization operations. Currently, the acid is used in a single cycle for the dissolution of residues since once the radioactive material has been recovered it is subsequently sent for treatment in a secondary radioactive liquid waste treatment facility. There it is further cleaned of radioactive materials prior to discharging it to the environment through a Clean Water Act (CWA) National Pollution Discharge Elimination System (NPDES) permitted outfall. The current permit allows for an unlimited amount of nitrates to be discharged via the liquid outfall, but a new permit is being negotiated with the State regulatory Department to meet domestic water supply standards that include a limit for dissolved nitrate of 10 mg/L as N. Thus, a nitrate destruction or nitrate recovery method must be incorporated into the process flow-scheme to allow for continued operation.

2.0 Objective

A preliminary assessment of the situation identified recycling and reusing the nitric acid in the recovery operations as an attractive and viable alternative to destruction of the acid to its elemental components. Distillation was selected as the most robust and technically viable unit operation to perform the recovery. However, it will require some unique applications because of the fissile nature of the radioactive materials that will be processed through the unit and the physical constraints imposed by the space available in the processing facility. The equipment is not required to be remotely operated as the radiation levels are low enough to allow direct contact. However, due to the toxicity of the radioactive materials, appropriate personal protective equipment (PPE) will be required to perform maintenance.

The task is then to provide a design proposal for the distillation unit complete with process controllers and an associated cost analysis. Also required is a concise hazard summary and demonstration that the selected design incorporates the appropriate safety systems and equipment maintenance for use with boiling nitric acid containing small amounts of alpha radioactive materials. .

The following format should be used to prepare the proposal:

<u>Report Body</u>

- Title Page.
- Table of Contents.
- Executive Summary: One page condensation of the report.
- Introduction: Restatement of the problem with background and objectives.
- Discussion: Present the alternative design options (i.e. plate vs. packing, materials of construction), evaluate the strengths and weaknesses of the various alternatives, define the basis of the final design, identify key operating points and special hazards including those

associated with handling radioactive materials. Provide all results and supporting calculations in SI units.

- Summary: Summarize the results of the analysis, conclusions and recommendations.
- Conclusions: Interpret your results and provide a structure that places the most important ones first.
- Recommendations: Clearly state the design specifications and safety requirements for the process chosen.
- Project Assumptions: State the design or economic assumptions or any important fabrication or inspection requirements, i.e., ASME pressure vessel code stamps or inspection requirements.
- Process Flow Diagram (PFD): Show a flow scheme with all major process equipment, and with a stream number for each major process stream. Show the basic process control instrumentation including points of measurement for temperatures, pressures, flow rates, pH, radioactive material content and other associated control devices.
- Mass and energy balances: Provide a mass and energy balance summary that includes heat input and cooling duties. For each stream on the PFD, report the stream number, description, composition (by weight fraction), temperature, pressure and flow rate (overall and by individual component). Include a table with the consumption of the utilities.
- Hazard and environmental analyses: Identify and discuss material, industrial and radiological hazards and the appropriate design or administrative controls.
- Equipment Summary: Provide a list of all equipment used in the process, including equipment type and description, operating limits, sizes, duties, estimated purchase costs, important fabrication specifications and materials of construction.
- Economic analysis: Include a discussion of the economic analysis and cost estimate of the final design.

Appendix

- Computer Simulators: While a simulator may be used, as indicated in the contest rules, the data presented in the problem is most applicable and thus it takes precedence over any simulator model calculations. An alternative could be to use a spreadsheet with the appropriate vapor-liquid data and estimate stages and liquid-vapor flows in the column. If this approach is used, then describe the program calculations, nomenclature, and the input and output files. The program should be documented with comments and cell formulas.
- Back-up data and hand calculations: Provide documentation in an attached appendix of any additional calculations or models used to set the final design. Also, provide nomenclature and all references used.

3.0 Stream Specifications

A simplified schematic and table is shown below:

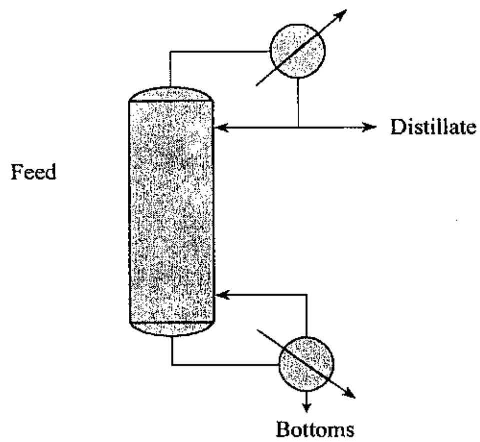

Table 1
Stream Specification for Distillation Column

Steam	Acid Concentration	Radioactivity
Feed at 3 liters/min	3 to 6 M	60 μCi/L total alpha
Distillate	10 ppm as N	< 0.5 μCi/L total alpha
Bottoms	> 12 M	-

Table 2
Plant Utility Interface Requirements

Plant Utility System	Typical Condition	Intended Use
Positive Pressure Chilled Water	Nominal 10^0 C at 100 psig (10 deg temp rise)	Condensor, Product Chiller
Compressed Air	Supply at 100 psig	Valve actuators
Steam	Saturated at 90 psig	Reboiler, Feed Preheater
Condensate Return	Cooled to 70^0 C prior to discharge	Reboiler, Feed Preheater
Industrial Water	Nominal 25^0C at 40 psig	Column Flush, Column Startup
Vacuum	- 18" Hg	Solution Transfer

4.0 Technical Data

Distillation (or fractionation) is a process in which a liquid or vapor mixture of two or more substances is separated into its component fractions of desired purity by adding or removing heat. Pure liquids have different volatilities, or vapor pressures, at a given temperature. If a liquid mixture is heated, the vapor will be richer in the more volatile substance. In this case, a binary liquid mixture of nitric acid and water will be separated with the acid fraction recovered at a usable concentration of >12M and the water fraction discarded. The water (boiling point of 100°C at 1 atm) is the less volatile substance and the pure nitric acid (boiling point at 87°C at 1 atm) is the more volatile component.

In this case, the nitric acid/water mixture is a very non-ideal solution that forms a homogenous, high-boiling azeotrope. A homogeneous azeotrope is a liquid mixture with a single phase that produces a vapor with the same composition as the liquid. Since distillation depends on generating a vapor that has a composition different from that of the liquid, homogeneous azeotropes cannot be separated by conventional distillation techniques. For nitric acid and water, such an azeotrope is formed at a 15.6M nitric acid concentration and it has a boiling point of 122°C at 1 atm. Thus, for dilute acid feed concentrations as in this system, the azeotrope represents the effective maximum product concentration using distillation.

Distillation is customarily carried out as a continuous operation in contact towers. The equipment consists of a vertical shell with trays or packing. The vertical shell is connected by suitable piping at the bottom to a heat exchanger, or reboiler, which provides the necessary energy input for the distillation operation. At the top, the vertical shell is connected to another heat exchanger or condenser that condenses and cools the overhead vapors. The shell together with the condenser and reboiler constitute a distillation column, or in this case an acid fractionator. Liquid flows by gravity from the top of the column and the overhead condensor to the bottom, the vapor rises up through the column from the reboiler. The purpose of the tray or packing is to intimately contact the vapor and liquid with the goal of reaching equilibrium.

The unit will produce at least 12M nitric acid as product and a pH 3 to 4 water stream for discard to the secondary treatment facility. The product nitric acid will be placed in suitable storage tanks and made available to the processing area for re-use. The low-level water stream (<0.5 μCi/L total alpha) will be sampled in tanks and then sent to RLWTF upon verification that the solution meets the waste acceptance criteria .

Table 3
Nitric Acid Vapor-Liquid Equilibrium Data at 1 atm

T (deg C)	x, nitric	y, nitric
100.000	0.000	0.000
104.000	0.067	0.003
104.500	0.072	0.003
106.500	0.102	0.010
107.000	0.110	0.012
108.500	0.135	0.020
109.500	0.141	0.023
110.500	0.162	0.035
111.500	0.181	0.042
112.000	0.181	0.042
114.500	0.217	0.082
115.500	0.233	0.096
117.500	0.282	0.165
119.200	0.348	0.297
119.400	0.341	0.259
120.000	0.383	0.375
119.900	0.374	0.375
118.500	0.450	0.564

Table 4
Cost Summary

Item	Cost
Electricity	$0.10 Kwatt
Steam	$21.00 per 1000 kg
Cooling Water	$0.03 per 1000 liter
Engineering Labor	$60.00 per hour
Operations Labor	$85.70 per hour
Maintenance Labor	$76.00 per hour
Solid Waste	$50 per kg
Liquid Waste	$0.10 per liter

Table 5
Capacity Factors

Item	Factor
Operating schedule	50 hrs per 7 day week, <12 hours per day
Feed Storage	5 hours of operation
Product Storage	20 hours of operation

Discard Storage	10 hours of operation

Table 6
Physical Constraints

Item	Constraint
Room Dimensions	13.5' H x 30' W x 30' L
Doorway	7'H x 3' W

5.0 References

Perry's Chemical Engineers Handbook (most recent edition)

Walas, S.M., Chemical Process Equipment: Selection and Design, Butterworth-Heinemann Series in Chemical Engineering 1990

Sinnot, R.K., Coulson and Richardson's Chemical Engineering Volume 6, Design, 2 ed. Pergamon Press 1993

Treybal, R.E., Mass Transfer Operations, McGraw-Hill Chemical Engineering Series, 1980

Standards of the Tubular Exchanger Manufacturers Assocation (TEMA), Eighth Edition

Zemaitis, J.F., Clark, D.M., Rafal, M., Scrivner, N.C., Handbook of Aqueous Electrolyte Thermodynamics, AIChE DIPPR, 1986