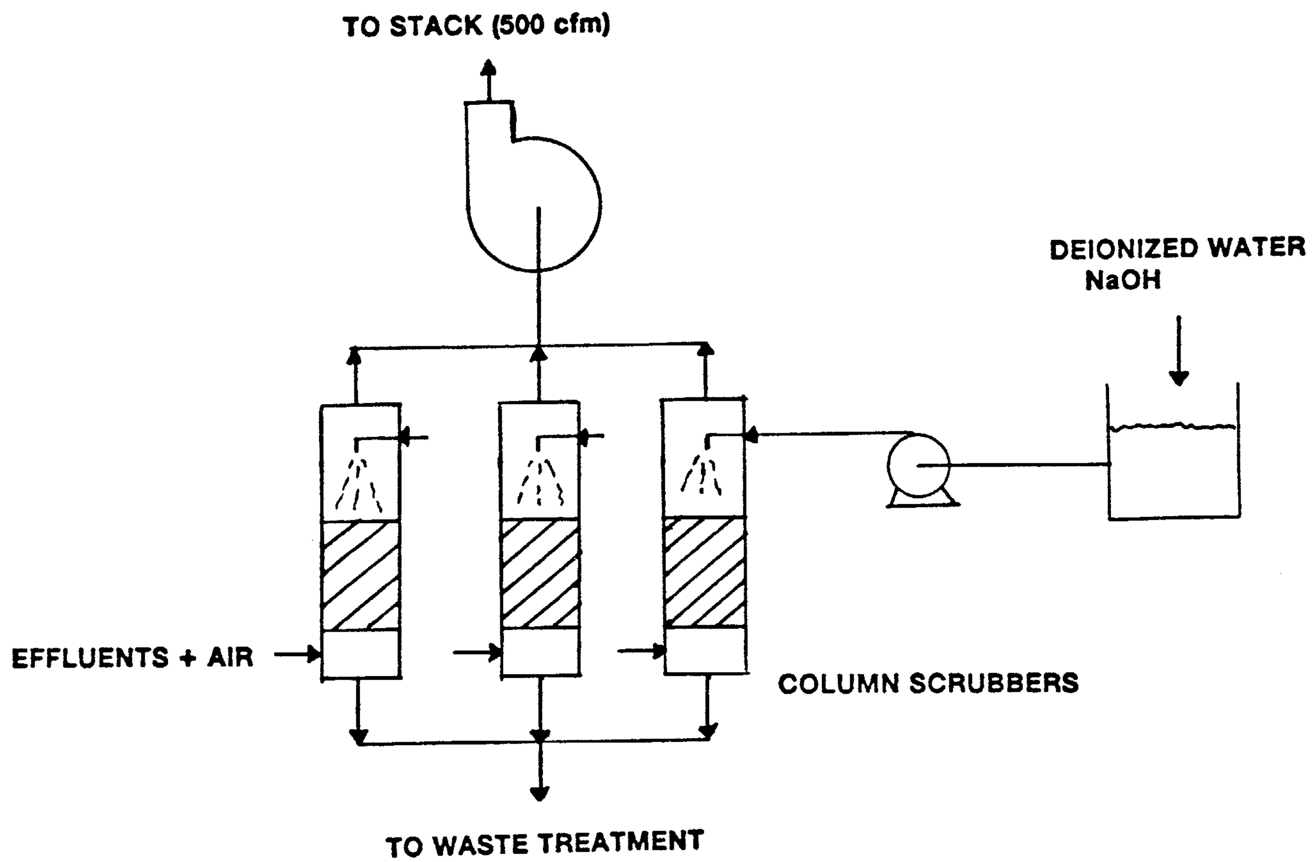
FIGURE 1. EXISTING SCRUBBING SYSTEM



ESTIMATING FIXED OPERATING COSTS

— Assume plant overhead costs will be 35% of the Raw Materials + Utilities costs.
— Assume administrative costs will be 5% of the fixed capital investment.
— Assume research and development costs will be 3% of the fixed capital investment.
— Assume insurance costs will be 1.5% of the fixed capital investment.

REFERENCES

1. Perry's Chemical Engineers' Handbook, Fifth Edition, McGraw-Hill, 1973.
2. Treybal, "Mass-Transfer Operations", Third Edition, McGraw-Hill, 1980.

American Institute of Chemical Engineers

STUDENT CONTEST PROBLEM

1990

345 East 47 Street • New York, New York 10017

Table IX

PURCHASED EQUIPMENT COSTS

EQUIPMENT ITEM	COST ($)
Packed bed absorber	16000 + D(1000 + 1500H) + D^2(2000 + 3000H)
Filter Press	30000 + N(2500)
Glass-lined pressure reactor	28000$(V)^{.57}$
Storage tank	3200$(V)^{.48}$
Agitated tank	10000$(V)^{.50}$
Misc. equip. (Pumps, sensors, level) controls, N_2 blanketing, etc)	0.1(Purchase Cost of Major Equipment)
Packing	0.5V

NOTATION

D	column diameter, m
H	column height, m
N	number of plates
V	volume, m^3

Table X

OPERATING COSTS

RAW MATERIALS	COST ($/kg)
NaOH (50% w/w)	1.67
HNO_3 (70% w/v)	0.32
HCl (gas)	0.13
HCl (36% w/w)	0.08
$MgSO_4$	0.58
H_2O_2 (30% w/v)	2.67
UTILITIES	**COST**
Deionized water	\$1.20/m^3
Refrigeration	\$8.60/million-kjoules
Liquid waste treatment	\$0.13/m^3
Solid (non-toxic) waste disposal	\$0.04/kg
Electrical, telephones, and other misc. items	\$100.00/day

Table VII

GAS PHASE MASS TRANSFER CORRELATION

$$\frac{F_G Sc_G^{2/3}}{G} = 1.195\left[\frac{d_s G'}{\mu_G(1-\epsilon_{Lo})}\right]^{-.36}$$

$$\epsilon_{Lo} = \epsilon - \phi_{Lt}$$

$$\phi_{Lt} = 0.05908 L'^{.331}$$

$$a = \frac{14.69(808 G'/\rho_G^{1/2})^n}{L'^{.111}}$$

where $n = 0.1114 L' + 0.148$

NOTATION

a	specific interfacial surface for mass transfer, m^{-1}
d_s	diameter of sphere of same area as a packing particle, m
D	diffusivity, m^2/s
F_G	gas phase mass transfer coefficient, $kmol/m^2 \cdot s$
G	superficial molar gas mass velocity, $kmol/m^2 \cdot s$
G'	superficial gas mass velocity, $kg/m^2 \cdot s$
L'	superficial liquid mass velocity, $kg/m^2 \cdot s$
Sc_G	Schmidt number = $\mu/\rho D$, dimensionless
ϵ	dry fractional void volume, dimensionless
ϵ_{Lo}	operating void space, dimensionless
μ_G	gas viscosity, $kg/m \cdot s$
ρ_G	gas density, kg/m^3
ϕ_{Lt}	total liquid holdup, dimensionless

Table VIII

FILTER PRESS SPECIFICATIONS

Capacity - 5 to 50 plates, 0.0283 m^3/plate (1 ft^3/plate)
Filter area - 0.929 m^2/plate (12.5 ft^2/plate)
Average filtration rate - 203 L/m^2-hr (5 gal/ft^2-hr)
Maximum filtration rate - 406 L/m^2-hr (10 gal/ft^2-hr)

1990 AIChE STUDENT CONTEST PROBLEM

DEADLINE FOR MAILING

Solution must be postmarked not later than midnight, June 1, 1990

RULES OF THE CONTEST
(Revised July 31, 1988)

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 except for those readily available in handbooks and similar reference works. The use of textbooks, handbooks, journal articles, and lecture notes is permitted. In cases where there is disagreement in the data reported in the literature, the values given in the problem have been chosen as being most nearly applicable.

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. Students are further advised that the problem can be solved without the use of sophisticated computer programs. Judging is based on the overall suitability of the solution, not on skills in manipulating computer programs.

The Student Contest Problem is designed to be solved by individual chemical engineering students working entirely alone, and it is judged on that basis. There are, however, other academically sound approaches to using the problem. The following confidentiality rules therefore apply:

1. ***For students 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 solution. Discussion with faculty and students at that school is permitted only after complete final reports have been submitted to the chapter counselor.

2. **For students whose solutions are not intended for the contest:**
   Discussion with faculty and with other students at that school 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 schools, or with individuals in the same school who are still working on the problem for the contest, until after June 1, 1990. 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 these conditions.

A period of not more than thrity days is allowed for completion of the solution. This period may be selected at the discretion of the individual counselor, but in order to be eligible for an award a solution must be postmarked not later than midnight, June 1, 1990. ONLY SOLUTIONS SUBMITTED BY NATIONAL STUDENT MEMBERS OF AIChE WILL BE CONSIDERED FOR AWARDS.

The finished report should be submitted to the chapter counselor within the thirty-day period. There should not be any variation in form or content between the solution submitted to the chapter counselor and that sent to the AIChE office. 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. Each counselor should select the best solution or solutions, not to exceed two, from his or her chapter and send these by registered mail to the institute.

Two copies of the solution(s) must be accompanied by a letter of transmittal giving only the contestant's name, school address, home address, home telephone number, and student chapter, lightly attached to the report. This letter will be retained for identification by the executive director of the Institute. The solution itself must bear no reference to the student's name or institution by which it might be identified. In this connection, graph paper bearing the name of the institution should be avoided. Original manuscript(s) must remain in the possession of the student chapter counselor, or faculty member, sponsoring the student(s).

As soon as the winners have been notified, original manuscripts for first, second, third and honorable mention categories must be forwarded to the office of the Executive Director as soon as possible.

Richard E. Emmert
Executive Director
American Institute of Chemical Engineers
345 East Forty-seventh Street
New York, New York 10017

Student chapter advisors and design course instructors are asked to contact the Chair of the Student Contest Problem subcommittee if they have any questions about the problem.

Dr. Jerald N. Linsley
Chair
1990 Student Contest Problem Subcommittee
of the Student Chapters Committee
Florida Institute of Technology
Chemical & Environmental Engineering Dept.
Melbourne, FL 32901-6988

Telephone Number: 407/768-8000, Extension 7560

FAX: 407/984-8461

Table IV
HEAT CAPACITIES

COMPOUND	EXPRESSION	UNITS
HCl (g)	6.70 + 0.00084T	cal/°K-mol
$GeCl_4$ (g)	8.61 + 0.00075T	cal/°K-mol
$GeCl_4$ (l)	28.5	cal/°K-mol
reaction mixture	1.24 + 0.00041T	cal/°K-g

Table V
Ge SOLUBILITY IN AQUEOUS HCl SOLUTIONS

Ge CONC. (mol/L)	HCl CONC. (mol/L)
0.04	5
0.005	6
0.001	7
0.0006	8
0.0004	9

Table VI
PACKING SPECIFICATIONS - CERAMIC RASCHIG RINGS

CHARACTERISTIC	VALUE	UNITS
Nominal Size	13	mm
Fractional void volume, dry (ϵ)	0.63	dimensionless
Specific surface area (a_p)	364	m^2/m^3
Packing factor (F_p or C_f)	580	dimensionless
Diameter of sphere of same surface as a single packing particle (d_s)	0.01774	m

Table I

AQUEOUS SOLUBILITIES OF Ge AND Si

pH	CONC. OF Ge (mg/L)	CONC. OF Si (mg/L)
4	4500	250
5	3800	200
6	3000	90
7	4400	70
8	15000	60
9	25000	90
10	30000	350
11	>35000	>10000

Table II

EFFLUENT SPECIFICATIONS

COMPOUND	TOTAL DISCHARGE FOR ALL PRODUCTION UNITS
$GeCl_4$	200 g/min
SiO_2	75 g/min
GeO_2	1 g/min
Cl_2	375 g/min
O_2	7 g/min

Table III

HEATS AND FREE ENERGIES OF FORMATION

COMPOUND	FREE ENERGY OF FORMATION, ΔG at 25°C (kcal/mol)	HEAT OF FORMATION, ΔH at 25°C (kcal/mol)
H_2O (l)	-56.7	-68.3
HCl (g)	-22.8	-22.1
HCl (aq)		-40.0
$GeCl_4$ (l)	-110.6	-127.1
$GeCl_4$ (g)		-119.2
$MgGeO_3$ (s)	-254.9	-275.5
GeO_2 (s)	-118.8	-131.7
mgcl2 (s)	-141.6	-153.4
mgcl2 (aq)		-191.5
$Mg(OH)_2$ (s)	-199.2	-221.0
$Mg(OH)_2$ (aq)		-221.5
NaCl (s)	-91.8	-98.3
NaCl (aq)		-97.3
NaOH (s)	-101.7	-100.6
NaOH (aq)		-112.4
$SiCl_4$ (l)	-148.2	-164.2
SiO_2 (s)	-204.4	-217.3
$MgSiO_3$ (s)	-349.5	-370.2

Based on elements in their standard states at 101 kPa and 25°C.

AIChE STUDENT CONTEST PROBLEM

1990

Recovery of Germanium from Optical Fiber Manufacturing Effluents

INTRODUCTION

The manufacturing process for making optical fibers involves high temperature oxidation of silicon tetrachloride ($SiCl_4$) and germanium tetrachloride ($GeCl_4$) to form glass particles (SiO_2 and GeO_2) which are incorporated into a glass preform rod. This rod is subsequently drawn in a furnace to produce optical fiber. Germanium tetrachloride is added to increase the refractive index of the glass core in the optical fiber preform. It is known from experimental studies that the oxidation of $GeCl_4$ to GeO_2 proceeds to only 25% completion whereas oxidation of $SiCl_4$ is nearly complete. In addition, particle deposition is only 50% efficient, resulting in further losses of germanium. Due to this loss and the high cost of germanium, a need exists for developing a process to recover germanium from optical fiber manufacturing effluents. For environmental reasons, the process design must also provide for the removal of chlorine and particles.

Your company currently operates with 50 preform manufacturing units. Each unit is equipped with a small packed column scrubber that is known to be underdesigned based on the current effluent production rates. The scrubbing solution is not recirculated and there is no recovery of germanium. Your engineering group has been designated to prepare a process design for a new scrubbing system to efficiently remove $GeCl_4$, Cl_2, and particles. You should also design a system to recover germanium and convert it to $GeCl_4$.

STATEMENT OF THE PROBLEM

Your assignment is to:

1. Synthesize the optimum flowsheet and material balance for the new scrubbing process, germanium recovery process, and germanium conversion process. (Final purification of the $GeCl_4$ is beyond the scope of your assignment.)
2. Determine the size and cost of the major pieces of equipment.
3. Estimate the installed equipment capital cost for the process.
4. Estimate the operating cost.
5. Calculate the discounted cash flow rate of return for the project based on the value of the recovered $GeCl_4$.

FINAL REPORT FORMAT

Your final report should include the following sections:

1. Cover letter.
2. Title page including your name and the date.
3. Table of Contents.
4. Summary Page - Present your results and conclusions in a clear and concise manner.

5. Introduction - Give a concise statement of the problem, covering background and objectives.
6. Discussion - Present the details of the work done. Include appropriate data, calculations, assumptions, and references. Tables and graphs need not be included in this section but should be referred to as attachments if they are essential for understanding the discussion.
7. Conclusions - List the major conclusions in decreasing order of importance. More detail should be given here than on the summary page.
8. Recommendations - Present your final recommended design. Include references to process flow diagrams, tables listing equipment and specifications, and tables giving material and energy balances. Summarize the process economics.
9. Attachments, Figures, Tables, and Appendices - Include any appropriate data, calculations, assumptions, diagrams, nomenclature, and references.

DESCRIPTION OF THE PROCESS

GENERATION OF EFFLUENTS

Vapors of $SiCl_4$ and $GeCl_4$ in an excess of oxygen are introduced into the optical fiber preform production units where the following reactions occur at high temperature:

$$SiCl_4 + O_2 \rightleftarrows SiO_2 + 2Cl_2 \quad (1)$$

$$GeCl_4 + O_2 \rightleftarrows GeO_2 + 2Cl_2 \quad (2)$$

Both reactions reach equilibrium which corresponds to 100% completion for reaction 1 and 25% completion for reaction 2. Incorporation of solid particles into the glass preform rod is only 50% efficient. The effluent stream therefore contains SiO_2 and GeO_2 particles, unreacted $GeCl_4$ and O_2, and the reaction product Cl_2.

SCRUBBING SYSTEM

Effluents from each preform production unit are drawn into small (0.25 m diameter, 0.5 m high) packed bed scrubbers as diagramed in Figure 1. The scrubbing liquid is an aqueous NaOH solution adjusted to pH 13. A single fan unit draws the effluents into the scrubbers. Due to operating requirements, it is not possible to make a tight seal between the effluent stream outlet and the inlet to the scrubbing system, hence the effluent stream gets diluted with a large amount of room air as it enters the scrubber.

Within the scrubbers, the $GeCl_4$ and Cl_2 are removed from the gas stream by absorption and converted to soluble species according to the following reactions:

$$GeCl_4 + 5OH^- \rightleftarrows HGeO_3^- + 4Cl^- + 2H_2O \quad (3)$$

$$Cl_2 + 2OH^- \rightleftarrows ClO^- + Cl^- + H_2O \quad (4)$$

The particles dissolve according to:

$$GeO_2 + OH^- \rightleftarrows HGeO_3^- \quad (5)$$

$$SiO_2 + OH^- \rightleftarrows HSiO_3^- \quad (6)$$

ECONOMIC DATA

GENERAL

— Assume construction of the facility will be completed in the period from July, 1991 through December 1991.

— Calculate the discounted cash flow rate of return based on production starting in 1992 and a service life of 10 years. Assume income based on the value of the $GeCl_4$ recovered even though it will not be sold outside the company.

— Determine the total operating costs as the sum of variable costs and fixed costs as outlined below.

— Assume that operating costs and value of recovered $GeCl_4$ will all escalate at 2.5% per year.

— Calculate depreciation using the straight line method over the 10 year service life.

— The 1990 value of pure $GeCl_4$ is $800/kg and the cost of purifying the product from this process is $100/kg.

— Ignore start-up costs.

— Ignore inflation and investment tax credit.

ESTIMATING CAPITAL COSTS

— Purchased equipment costs are given in Table IX. Assume the data are for the appropriate materials of construction.

— The installed equipment cost can be estimated by multiplying the sum of the purchased equipment costs by the Lang factor (=5). The installation costs for the existing glass-lined reactor and condenser are $160000.

— Assume working capital will be 10% of the total capital investment.

— Assume no spare items are required.

— Assume the existing small scrubbers can be removed at a cost of $50,000.

— Ignore costs for NaOH, HNO_3, H_2O_2, and $MgSO_4$ storage tanks.

ESTIMATING VARIABLE OPERATING COSTS

— Raw Materials and Utility costs are given in Table X.

— Operating labor cost is $25 per man-hour. The existing scrubbing system requires 2 operators per shift. Assume that only one operator would be required if the small scrubbers were replaced with a single scrubbing unit. Assume that 3 operators are required for the germanium recovery and conversion facility.

— Supervisory and clerical labor costs are 30% of operating labor costs.

— Laboratory and other support services equal 5% of the Raw Materials + Utilities costs

— Assume the cost of maintenance and repair will be 8% of the fixed capital investment if the small scrubbers are retained. This drops to 4% if a single scrubber system is used.

— Assume operating supplies will be 1% of the fixed capital investment.

- Assume that if the above requirements are satisfied, then 100% of the particles will be removed from the gas stream and will dissolve according to reactions 5 and 6.
- Use 13 mm (0.5 inch) ceramic Raschig rings for packing (see Table VI).
- Assume that the existing fan is suitable for the new scrubbing system and that the total gas flow exiting the fan is 14.2 m^3/min (500cfm) at 25°C and 101 kPa.
- Design the absorption tower to use a liquid flow rate equivalent to 75% of flooding. Use the flooding correlation given in the Chemical Engineer's Handbook (ref. 1, Figure 18-39). The same correlation is also available in reference 2 (Figure 6.34).
- Assume packed bed columns are available in sizes starting at 0.305 m (1 ft) diameter and increasing in increments of 0.153 m (0.5 ft).
- Use the correlation given in Table VII to calculate the gas phase mass transfer coefficient.

GERMANIUM PRECIPITATION

- Calculate the bleed stream flow rate such that the steady state concentration of Si in the recirculating scrubber loop is maintained at 3.0 g/L.
- Assume washing filter presses are available with recessed plates each holding 0.0283 m^3 (1 ft^3). See Table VIII for further specifications.
- Assume all filtrations produce a cake with 30% (w/v) solids and a wet density of 1.2 kg/L.
- Cake should be washed with deionized water equivalent to four times the filter press capacity.
- Assume 95% of the dissolved solutes are displaced by washing.
- Assume wash flow rate is equal to the average filtration rate.
- Precipitation reactions are to be performed in stirred tanks with a minimum residence time of 10 minutes.
- Adjustments of the solution pH should be done with NaOH (50% w/w) or nitric acid (70% w/v).
- Design the bleed stream storage tank to hold 4 days worth of flow.

GERMANIUM CONVERSION

- Assume a 1.89 m^3 (500 gallon) glass-lined and agitated reactor with a pressure maintaining valve and suitably sized condenser are available at no capital cost.
- Assume the reactor operates at a temperature equal to 75% of the maximum (adiabatic) temperature.
- Assume the gas from the reactor is isothermally reduced in pressure from 202 kPa to 101 kPa before entering the condenser.
- Gas leaving the condenser is at 101 kPa and 0°C.
- Design the storage tank for $GeCl_4$ product to hold one week's capacity.

For this study, you must design a secondary scrubbing system to improve the overall efficiency for removing $GeCl_4$, Cl_2, SiO_2, and GeO_2. The new scrubber should be a single packed tower absorption unit with a recirculating liquid stream. You must decide whether it is better (economically) to design a packed tower to handle the combined effluents from the existing small scrubbers or to remove the existing scrubbers and design a larger packed bed tower. Assume that the effluents from each preform production unit can be routed into a central pipe that feeds the packed tower. Your design should include equipment and controls for maintaining the scrubbing liquid at pH 12 or greater with addition of NaOH. Hydrogen peroxide (H_2O_2) must also be added to reduce hypochlorite according to:

$$ClO^- + H_2O_2 \rightleftarrows Cl^- + H_2O + O_2 \qquad (7)$$

Technical, economic, and process design information for the effluents and scrubbing system are provided in greater detail below.

GERMANIUM RECOVERY

The R&D department has found through experimental research and from information available in the literature that germanate ($HGeO_3^-$) can be quantitatively removed from solution by precipitating with a divalent cation such as Mg^{2+} according to:

$$Mg^{2+} + HGeO_3^- \rightleftarrows MgGeO_3(ppt) + H^+ \qquad (8)$$

Similarly, silicate ions are precipitated according to:

$$Mg^{2+} + HSiO_3^- \rightleftarrows MgSiO_3(ppt) + H^+ \qquad (9)$$

This suggests that a convenient means for collecting the germanium is to remove a bleed stream from the recirculating scrubbing system, add magnesium sulfate ($MgSO_4$) in a stirred tank to form the magnesium germanate, and then collect the precipitate by filtration. Experiments have shown that $HGeO_3^-$ and $HSiO_3^-$ are precipitated equally well and that a mole ratio of 1.25 to 1 for Mg to total of Ge + Si is required to precipitate 100% of the Ge and Si. The remaining Mg is precipitated as $Mg(OH)_2$ according to:

$$Mg^{2+} + 2OH^- \rightleftarrows Mg(OH)_2(ppt) \qquad (10)$$

For this study, you are to design a process to recover germanium from the recirculating scrubber liquid as magnesium germanate. All solid-liquid separations will be done with filter presses. The R&D department has also measured the solubility of Ge and Si in scrubbing solutions at various pH values. The results are presented in Table I, and may be useful in the design of a germanium recovery system.

GERMANIUM TETRACHLORIDE PRODUCTION

Wet precipitate cake containing $MgGeO_3$ is to be used as a feed to make $GeCl_4$ which, after purification, can be used in optical fiber production. The tetrachloride is formed according to:

$$MgGeO_3 + 6HCl \rightleftarrows GeCl_4 + MgCl_2 + 3H_2O \qquad (11)$$

Additional reactions that may or may not be important include:

$$MgSiO_3 + 6HCl \rightleftarrows SiCl_4 + MgCl_2 + 3H_2O \quad (12)$$

$$MgGeO_3 + 2HCl \rightleftarrows GeO_2 + MgCl_2 + H_2O \quad (13)$$

$$MgSiO_3 + 2HCl \rightleftarrows SiO_2 + MgCl_2 + H_2O \quad (14)$$

$$Mg(OH)_2 + 2HCl \rightleftarrows MgCl_2 + 2H_2O \quad (15)$$

$$NaOH + HCl \rightleftarrows NaCl + H_2O \quad (16)$$

Using the standard enthalpy and free energy values provided below and assuming that the above reactions proceed quickly to equilibrium, you are to design a reactor and condenser system to form and collect $GeCl_4$. Estimate the final product purity. A glass-lined, agitated reactor (capacity = 1.89 m^3, 500 gallons) and condenser are available within the company at no capital cost (consider only installation costs.) Use this reactor if the capacity is suitable, otherwise specify a new reactor of the appropriate size.

The reaction is to be run in the following, batch-wise manner:

1. Load wet cake into reactor.
2. Evacuate air space.
3. Introduce HCl as gas (pure) or liquid (36% w/w) with agitation over 30 minutes.
4. Maintain pressure in reactor at 202 kPa by venting gases through a pressure maintaining valve.
5. Condense $GeCl_4$ from released gases in a condenser operating at 0 °C and 101 kPa pressure. Collect in a storage tank maintained with a nitrogen blanket.
6. After 60 minutes, divert gases from reactor into the gas scrubbing system and purge with nitrogen.
7. Flush reactor contents with water and send to waste treatment facility.

TECHNICAL DATA

Data from the literature and from tests performed by your R&D organization suggest the following guidelines to use as a basis for design calculations:

EFFLUENT SCRUBBING

— Effluent specifications are given in Table II.

— Assume isothermal operation of scrubbers at 25°C.

— Scrubbing solution should not drop below pH 12.

— Air entering the scrubbers is at 50% relative humidity and 25°C, air leaving the scrubber is at 100% relative humidity and 25°C.

— Use data on air to estimate values for gas density and viscosity.

— Use data on NaOH solutions to estimate liquid density and viscosity.

— For mass transfer calculations assume the equilibrium distribution curve relating gas phase mole fraction (ordinate) to liquid phase mole fraction (abscissa) is a straight

line of slope 0 for both Cl_2 and $GeCl_4$ (rapid, irreversible reactions). Also assume dilute solutions and that the primary resistance to mass transfer is in the gas phase.

— Diffusivity for Cl_2 is 0.000013 m^2/s at 25°C.

— Diffusivity for $GeCl_4$ is 0.000006 m^2/s at 25°C.

GERMANIUM PRECIPITATION

— Assume addition of $MgSO_4$ causes 100% precipitation of Ge, Si, and Mg according to reactions 8-10 when the mole ratio of Mg to [Ge + Si] is 1.25 to 1 and the final solution pH is 8 or greater. Essentially no Mg^{2+} ions remain in solution.

— The solubility of Ge and Si in the scrubbing solution as a function of pH is presented in Table I. Assume that these data were obtained in the presence of $MgCl_2$.

GERMANIUM CONVERSION

— Assume all reactions reach equilibrium quickly.

— Use the standard enthalpy and free energy values provided in Table III.

— Heat capacity values for various liquids and gases are presented in Table IV.

— Assume no water is present in the gases above the reaction mixture, i.e. it is composed of $GeCl_4$ and HCl only.

— Assume the vapor-liquid equilibrium concentration of HCl is given by Henry's Law where the Henry's Law coefficient is:

$$H(kPa) = 0.133e^{[2.03 + 0.0536T]} \quad (17)$$

T is temperature in degrees C.

— Assume the density of the reaction mixture is 1.15 kg/L and the heat capacity of the reaction mixture is constant with time and given in Table IV.

— The boiling temperature of $GeCl_4$ is 84°C at 101 kPa.

— The equilibrium concentration of Ge in aqueous HCl solutions is given in Table V. Assume these data were obtained under conditions identical to those found in the reactor (i.e. same T, P, and $MgCl_2$ concentration.)

DESIGN DATA

GENERAL

— Assume preform production units operate 24 hours per day, 335 days per year.

— Assume germanium recovery and conversion processes are to be operated once a day (8 hour shift), 7 days per week, 335 days per year.

EFFLUENT SCRUBBING

— Existing column scrubbers remove 95% of $GeCl_4$, 75% of Cl_2, and 50% of particles.

— Existing column scrubbers consume 1.89 L/min (0.5 gpm) of solution.

— The new scrubbing system should remove 99% of both $GeCl_4$ and Cl_2.