CHEMICAL ENGINEERING
PROCESS DESIGN AND ECONOMICS

A PRACTICAL GUIDE

SECOND EDITION

Web References

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Web References

Chapter 1

Page 18 - Teaching Design workshop comments on simulation.

Some "penalties" of teaching simulation in the capstone process design course were listed by C. S. Howat [2002] (www.engr.ukans.edu/~ktl) in his recap of the Design Instruction workshop that he hosted at the 2002 Annual AIChE meeting. He summarized a discussion conducted among participants on the topic of simulation with this conclusion

"Ineffective use of software can be an impediment to, instead of a vehicle for, meeting course objectives."

His illustrative slide continues:

"Simulator use typically requires a significant increase in student time required to solve the problem-it plays to the weakest characteristics of student (& faculty).

1. It takes less mental effort to arbitrarily modify a specification than it does to think of the significance of the constraint failure, the impact of the projected change, constraint value of the anticipated results and then to simulate.

2. It takes significantly less effort to use the library database than it does to collect primary data, evaluate suitability, and develop a data base.

3. It takes significantly less effort to alter database specifications than it does to evaluate specifications and develop an understanding on non-closure.

4. It takes significantly less effort to alter the simulation specifications flowsheet than it does to understand the underlying fundamentals, generalize and then simulate to confirm.

5. It takes significantly less effort to continually press *'Enter'* than it does to make sound engineering estimates and confirm.

The potential penalties in meeting course objectives are significant because the downside is so alluring to students and faculty.

Careful forethought and planning are required. "

Chapter 2

Trash to Energy University/Community Scenario

Refer to page 26 of the text

The trash-to-energy furnace was housed in the heating plant a building that also contained several boilers burning number 6 (residual or heavy) fuel oil. These boilers generated a significant amount of fly ash, and they were not fitted with dust collectors. Fly ash concentrations were too low to be visible under normal operating conditions, but over a period of time, ash collected on heat exchanger tubes in the exhaust duct. Eventually, the ash coating reduced heat transfer efficiency to a point where it had to be removed by directing jets of high-pressure steam at the tubes. (This is a common practice in boiler operation known as "soot-blowing," but the resulting ash is usually removed from the exhaust by dust collectors.) Because there were no dust collectors in this system, soot blowing was normally done at night when the black plume issuing from the chimney would not be visible. Occasionally, when efficiency became intolerably low, soot-blowing occurred in the day time.

On one of these occasions, environmentally-conscious students became alarmed and indignant, but they thought the pollution was coming from the "incinerator" (trash-to-energy plant). This led to a series of accusations that culminated in an expose' published in the student newspaper. The article was accompanied by a photograph showing an intense, black plume issuing from the smokestack. Anyone familiar with the heating plant would know that this tall brick smokestack in the center of the photograph handled exhaust from the oil-fired boilers only. The photographer unknowingly included the trash-to-energy chimney in the lower left of center which had no visible plume.

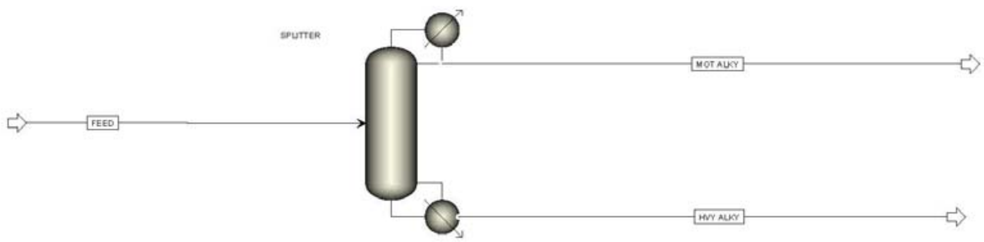
Academic administrators, who knew little about what occurred within the walls of the heating plant, were ill-prepared to voice an effective defense. In fact, a complete, honest analysis would have emphasized irresponsible pollution caused by the heating plant. Officials were also weary of complaints about truck traffic and other problems associated with hosting this semi-commercial project on campus. This may have prompted them to welcome the trash-to-energy plant as a scapegoat to divert attention from other problems.

A copy of Ulrich's whimsical fable written about these happenings and for the student newspaper is reproduced below:

Ulrich, Gael D. (1991), "The Tragedy of Trashte," The *New Hampshire*, Part I; p. 23 (February 12 issue) and Part II; p. 17, Durham, N.H. (February 15 issue).

Chapter 3

Refer to page 50



Alkylate Splitter				
Stream ID		FEED	HVYALKY	MOTALKY
From			SPLITTER	SPLITTER
To		SPLITTER		
Phase		LIQUID	LIQUID	LIQUID
Substream: MIXED				
Mass Flow	kg/sec			
BUTANE		.0626326	8.6560E-10	.0626326
N-PEN-01		.4956421	1.57655E-7	.4956420
N-HEX-01		.3366280	2.30846E-6	.3366257
N-HEP-01		.4319120	1.05907E-4	.4318061
2,3,4-01		11.23224	.0237208	11.20852
N-NON-01		1.261150	.2067225	1.054427
N-DEC-01		.8241127	.6231113	.2010015
N-UND-01		.1052740	.0991379	6.13603E-3
N-DOD-01		.1606093	.1580083	2.60098E-3
N-TRI-01		.1490015	.1485762	4.25295E-4
N-TET-01		.2405067	.2403562	1.50519E-4
N-PEN-02		.2002865	.2002584	2.80133E-5
Total Flow	kmol/sec	.1346977	.0107218	.1239758
Total Flow	kg/sec	15.50000	1.700000	13.80000
Total Flow	cum/sec	.0246694	2.93366E-3	.0218248
Temperature	K	393.1500	481.5203	388.3847
Pressure	N/sqm	1.71325E+5	1.91325E+5	1.61325E+5
Vapor Frac		0.0	0.0	0.0
Liquid Frac		1.000000	1.000000	1.000000
Solid Frac		0.0	0.0	0.0
Enthalpy	J/kmol	-2.2849E+8	-2.5512E+8	-2.2433E+8
Enthalpy	J/kg	-1.9857E+6	-1.6091E+6	-2.0154E+6
Enthalpy	Watt	-3.0778E+7	-2.7354E+6	-2.7812E+7
Entropy	J/kmol-K	-8.0304E+5	-9.8040E+5	-7.8564E+5
Entropy	J/kg-K	-6978.536	-6183.531	-7058.033
Density	kmol/cum	5.460109	3.654782	5.680500
Density	kg/cum	628.3086	579.4803	632.3081
Average MW		115.0725	158.5548	111.3120
Liq Vol 60F	cum/sec	.0216033	2.28514E-3	.0193201

Figure 1: Simulator-generated "flowsheet" for alkylate splitter module.

Beta-Galactosidase Simulation Calculations
Refer to page 60 of the text

Petrides and coworkers kindly provided access to their simulation software designed for analysis of batch processes (Petrides [2000]). Coauthor Vasudevan used this software to repeat Ulrich's manual analysis described above.

Preparation

Although familiar with bioprocessing, Vasudevan required many hours to read the software manual and become familiar with how unit operations were specified, how data are transmitted, and with other tasks required to use the program intelligently. For this problem, he needed to specify raw materials, and set up the flow sheet. These steps were straightforward and quickly accomplished from data given in the problem statement.

Next, each procedure and operation was initialized by specifying the action (i.e., "transfer," "react," "hold," etc.) and its sequence in the schedule. Each operation is initialized by the use of tabs for operating conditions, emissions, labor, and scheduling. In scheduling, for example, a user specifies start time of one operation relative to the end of another. Transfer times, processing times, setup, and turnaround times, starting time, and number of cycles are also specified.

A user also gives material balance specifications such as the amount of water, nutrients, and other additives per batch plus stoichiometric coefficients in the fermenter. Once these data have been provided, it is a simple task to solve mass and energy balance equations, and generate any number of "reports."

Function

Quoting Professor Vasudevan, "Setting up the flow sheet was fairly easy, and in the 'design' mode, the simulator is easy to run. The challenge is in understanding and knowing the limitations of each unit procedure. It is important for students to be familiar with the sizing options available and to gain a thorough understanding of the underlying design equations and models." Click here to see Professor Vasudevan's complete comments.

Once set up, the program is powerful and flexible. Users can vary parameters such as the extent of protein denaturation during centrifugation or ultrafiltration. Questions such as "How long does a single batch take? How many batches can be carried out in a year? Where are the bottlenecks?" can be answered quickly. Economic information not relevant to this chapter but crucial to the design is also obtained quickly and easily from the program.

CHAPTER 4

Refer to page 313

Alkylate Splitter Module Simulation Calculations

Coauthor Vasudevan performed a separate analysis of the alkylate splitter using a popular simulation program licensed to the University of New Hampshire. This commercial software included two distillation sub-packages. One uses the Winn, Underwood, Gilliland (WUG) technique (similar to that recommended in Chapter 4) for shortcut design of single-feed, two-product distillation columns with partial or total condenser. It assumes constant molal overflow and constant relative volatility. The second subprogram uses a more rigorous tray-to-tray (TT) or incremental column analysis that does not require these simplifying assumptions. Both subroutines calculate minimum number of stages, minimum reflux ratio, and the reflux ratio required for a specified number of stages (or conversely, the number of stages for a specified reflux ratio). Results also include optimum feed stage location and condenser/reboiler duties.

As with the β-Galactosidase simulation, Vasudevan spent many hours becoming familiar with the software. In questioning him, I was surprised that so much information was required of the user and that results were rather limited. For example, with feed pressure specified, I had expected column bottom and top pressures to come automatically from the software. Instead, Vasudevan found it necessary to input my values.[1]

I was also surprised to find that Vasudevan, a most computer-literate colleague, could not easily simulate the complete module with this software. Tower, reboiler, and condenser come conveniently as a unit, but modeling the entire alkylate splitter module, including other heat exchangers and pumps (as shown in Figure 4-50) is difficult with this software or would require much more time and energy than was available.

Choosing from among the many options offered by this software proved to be a major challenge as well as a luxury. For example, vapor liquid equilibrium data sources range from assumed ideal gas/ideal solution behavior to

[1]The same feed pressure for both manual and computer calculations is necessary to place results on the same basis, but one might expect bottoms and distillate pressures to be delivered independently by simulation software.

fugacities and activities calculated from any of several thermodynamic correlations.

Vasudevan's initial results are shown in Table 1 along with comparable results from my hand calculations.[2] Columns 2 and 3 show results obtained via WUG for the same reflux[3] ratio but using two different sources of data. Column 4 was obtained using the same software and data as column 2 but with number of ideal stages as the control or specified variable. Column 6 shows results from the TT sub-package based on the same input data as column 4.

TABLE 1 Simulator results for alkylate splitter D-120 compared with hand calculations of Ulrich (from Appendix G-1).

Analysis Tool	**Simulation using Winn, Underwood, Gilliland (WUG) Approach**			**Ulrich hand calculations**	**Simulation using Tray-to-Tray (TT) Approach**
Source of Thermodynamic Data	Chao-Seader Equation	Ideal Gas/Ideal Solution	Chao-Seader Equation	Fugacity correction factors based on Lee/Kesler charts	Chao-Seader Equation
Minimum Reflux Ratio	0.34	0.3	0.34	0.23	0.34
Actual Reflux Ratio	0.5	0.5	0.37	0.3	0.63
Control or Specified Variable	Actual reflux ratio = 0.5	Actual reflux ratio = 0.5	Number of ideal stages = 20	Actual reflux ratio = 0.3	Number of ideal stages = 20
Minimum Theoretical Stages	4	3.7	4	5.2	4
Actual Theoretical Stages	8.8	7.7	20	16.7	20
Number of Theoretical Stages above Feed	2	1.8	4.5		6
Tower Specifications				22 meter vertical tower, 2.2 meters in diameter, packed with 19 meters of 70 mm stainless steel metal Intalox (IMTP) packing.	
Feed Temperature (°C)	180	180	180	120	180
Distillate Temperature (°C)	118	114	118	115	118
Bottoms Temperature (°C)	200	196	200	186	214
Feed Pressure (barg)	0.7	0.7	0.7	0.7	0.7
Distillate Pressure (barg)	0.6	0.6	0.6	0.6	0.6
Bottoms Pressure (barg)	0.9	0.9	0.9	0.9	0.9
Condenser Duty (kJ/s)	6,220	6,410	5,433	5,800	7,278
Reboiler Duty (kJ/s)	40	20	748	5,200	1,132

[2]Stream compositions are not included in the Table because, based on the same input data, they were virtually the same for all cases.

[3]1.5 times minimum. This is somewhat larger than the range of 1.2 to 1.3 times minimum recommended in Table 4-19. The value in column 6, about 2 times minimum, is even further from the recommended optimum range.

On first examination, differences among minimum reflux values in this Table troubled me.[4] Dictated by equilibrium data and boundary conditions alone, simulation results and hand calculations should be closer. (A pseudo-binary check mentioned in Appendix G-1 also confirms the manual result.)

I next noticed that reboiler duty was a small fraction of condenser duty in all simulation results. With liquid streams entering and leaving at roughly the same average temperature, reboiler and condenser duties should be almost identical.[5] In this situation (partially-vaporized feed), manual results (reboiler duty slightly smaller than condenser duty) make sense. Simulation results do not.

Then I observed the difference in feed temperatures (simulation temperatures were reported in Kelvins, so the discrepancy was not as striking as it is in Table 1). Obviously, simulation results are for an all-vapor or mainly-vapor feed. This explains the minimum reflux problem. With a q-line nearly horizontal rather than nearly vertical, minimum reflux must be greater. At this point, I had no size specifications for the simulated distillation tower. If faithful to Table 1, its rectifying section should be much larger in diameter than stripping section, because there is almost no vapor load, and little liquid load in the bottom of the tower.

Markedly different actual reflux ratios between WUG and TT designs (columns 4 and 6 of Table 1) are troubling. Having the same minimum reflux ratio and using the same equilibrium correlations, one would expect actual reflux values to be closer. Assuming TT is more rigorous, this suggests that the Winn, Underwood, Gilliland technique is faulty. Confidence in TT results is also undermined, however, by a reboiler temperature that exceeds other results by 14°C or more. Based on a bubble-point calculation, bottoms temperatures should be identical when based on the same composition and pressure. This is especially pertinent to WUG and TT results (columns 4 and 6) using the same Chao-Seader equation of state.

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[4]Differences between numbers of minimum theoretical stages is also a concern. Strictly a function of the equilibrium curve and terminal concentrations, those values of N_{min} obtained via simulation (except that based on the ideal gas assumption) should be the same as the hand-calculated result. Since the Lee/Kessler charts are beyond reproach, N_{min} results in Table 1 suggest the Chao-Seader correlation is little better than an ideal gas assumption in this case.

[5]To understand this, envision an overall energy balance on a distillation system. Heat added in the reboiler (except for losses) must be removed in the condenser (or conversely, most of the heat removed by the condenser must come from reboiler).

At this point, I reported these concerns to Vasudevan. Selected extracts from our subsequent email dialogue illustrate both the power of simulation and how hand calculations, judgment, and experience are needed to temper its use.

Vasudevan: I did a bubble point/dew point analysis of the feed with these results:

Temperature (°C)	120	125	127	130	140	150	180
Vapor %	0	1.6	5	12	56	87	100
Liquid %	100	98.4	95	88	44	13	0

As you can see, the feed is predicted to be 100% liquid at a temperature of 120°C and100% vapor at 180°C.[6] Unfortunately, I can't get the program to yield a solution for feed temperatures below 140°C.

Ulrich: As noted in Appendix G-1, I found a feed bubble point of 104°C and dew point of 129°C. Your values 120 to 180°C are not too inconsistent with mine, although the spread is wider than I would expect. Feed at 120°C with 15% vapor shown in my flow sheet was a quick estimate. The vapor fraction is important to satisfy the energy balance, accuracy in its temperature, on the other hand, isn't necessary for preliminary equipment design.

Vasudevan: With TT,[7] I can "move" feed tray location down until a temperature of 120°C to 127°C is accepted. For feed entering on tray 14 at a temperature of 127°C: Actual Reflux Ratio is 0.34. Condenser and reboiler duties of 5,993 J/s and 5,855 J/s respectively are much more realistic.

What was the feed tray location in your calculations?

Ulrich: I did not determine feed tray location. It's not necessary for tower height/diameter specification, so I never bothered. In theory, one shouldn't need feed tray location for simulation calculations either. With feed composition and thermal condition fixed, the program should be able to find minimum reflux and, with an arbitrarily-specified reflux ratio greater than minimum, calculate number of theoretical trays. Feed location, that tray where composition matches feed composition, should be a result not a specification. Fourteen theoretical stages from the top is too many to agree with my results, although 14 actual stages might be reasonable. Your most recent condenser and reboiler duties are certainly consistent with hand

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[6] This confirms the diagnosis that all initial simulation results in Table 1 were for vapor feed. These numbers are also consistent with hand calculations.
[7] With the WUG subprogram, feed tray location cannot be specified independently.

calculations. The way this simulation answer is developed troubles me. It seems like a trial and error search. One should be able to simply specify feed, distillate, bottoms compositions, pressures, and feed temperature. Then, the simulation software should give minimum reflux ratio, actual reflux ratio versus number of trays (theoretical and actual), reboiler and condenser duties, optimum feed tray location, etc. with no other input from the programmer.

Vasudevan: I spent two and one-half days on the simulation program. With the Lee/Kessler equation of state, I was able to specify a feed temperature of 120°C. You will notice, however, that minimum reflux ratio is now 0.022. I am not sure what is going on with the minimum reflux ratio calculation. There appears to be an order-of-magnitude difference between the program and your hand calculations. Is it possible that your calculations are off by a factor or 10?

Ulrich: It is always possible that I made a mistake in reflux calculations, but I do note that my calculations of 20 years ago (details of which are long lost) led to the value on page 319 of the first edition which is 7.4/21.2 = 0.35 for actual reflux. It is interesting that Lee-Kessler gives you more flexibility in the software. But, how can changing the source of data expand the range of allowable feed temperatures unless alternate sources are in error? Shouldn't all data sources, if reliable, give the same result? It's not a question of which data source gives an answer that agrees with mine but a question of what answer is correct. How would a user know which is correct?

Vasudevan: Interesting point! This problem is with WUG not TT. The software developer certainly claims that TT is the more rigorous model. However, when we think in terms of a logical progression from hand calculations to WUG and then TT, I can see that this could cause a lot of confusion.

Ulrich: Of course there still remains the question of the large discrepancy between my hand calculations and simulation results.

Vasudevan: I checked your calculations in Appendix G and they seem to be OK. I believe this discrepancy stems from your exclusion of C_9 in the preliminary analysis. This is a class 2 separation where one or more components appear in only one of the products. Since there are 2 pinch points and since the assumptions of constant relative volatility and constant molar overflow are not valid, there are two roots of phi, and each root lies between an adjacent pair of relative volatilities of distributed components.

Ulrich: I was troubled about the problem of a distributed C_9 also, but went ahead anyway with the Underwood approach. I was somewhat reassured when the pseudo-binary result agreed closely. I am still uncomfortable, of course, with the discrepancy between simulation and hand calculations.

Vasudevan: Based on more recent relative volatilities, I get a negative minimum reflux, which suggests that a rectifying section is not required to obtain the specified separation.

Ulrich: If that result is correct, would you not recommend a different design; one with liquid superheat and a flash evaporator followed by a much smaller and less expensive stripping column? That would save a lot of capital.

Vasudevan: True, simulation results indicate a rectifying section is not required. With a feed temperature of 120°C, the actual number of stages is about 9 in a stripping section. Condenser and reboiler duties are around 5,400 kJ/s, and actual reflux ratio is about 0.2. With this, according to TT, light and heavy key recoveries are equal or better than specifications.

Ulrich: I was being facetious. I still believe the rectifying section is necessary despite what simulation is telling us. Can you provide specs like tower diameter, height, and cost for your final simulation result? With a reflux ratio of 0.2 and very low vapor/liquid rates, a stripping column below a flash drum should be quite small. Reboiler duty should now be quite small also, but a heavy-duty preheater/vaporizer will be necessary in the feed line to provide flash enthalpy.

Vasudevan: For a column packed with metal Intalox packing, the software specifies a packed height of 19 m for 16 theoretical stages, 75 mm nominal packing size, maximum fractional capacity = 0.62. In addition, one gets a printout of column hydraulics including pressure drop and liquid hold-up in every stage.

Ulrich: Is possible to get a single comprehensive flow sheet/streamchart document from the software?

Vasudevan: I was able to print out the document attached (see Figure 1). It is theoretically possible to include heat exchangers, pumps, etc, but this can be a nightmare. Convergence becomes a major headache because of problems with tear streams. Unless the right tear stream is chosen, convergence is not easy. I am still struggling with this.

Ulrich: Perhaps we should simply drop the problem in the laps of readers without resolving it. We could report the simulation design on one hand and manual results on the other and let someone more familiar with this process resolve the dilemma.

Supplementary Dialogue

Vasudevan: The Lee/Kessler/Plocker equation of state is available in this simulation package. I was surprised to find that I could run WUG successfully even when I specified a feed temperature of 120°C (both Chao-Seader and ideal gas models gave errors). Results are shown in Table 2.

TABLE 2 Simulator results for alkylate splitter D-120 with equations of state compared with hand calculations of Ulrich (from Appendix G-1).

Analysis Tool	**Simulation using Winn, Underwood, Gilliland (WUG) Approach**		**Ulrich hand calculations**
Source of Thermodynamic Data	Lee/Kessler/Plocker	Chao-Seader Equation	Fugacity correction factors based on Lee/Kesler charts
Minimum Reflux Ratio	0.022	0.012	0.23
Actual Reflux Ratio	0.058	0.046	0.3
Control or Specified Variable	Actual number of equilibrium stages = 17		Actual reflux ratio = 0.3
Minimum Theoretical Stages	4.2	4	5.2
Actual Theoretical Stages	17	17	16.7
Number of Theoretical Stages above Feed	4	4	
Tower Specifications			22 meter vertical tower, 2.2 meters in diameter, packed with 19 meters of 70 mm stainless steel metal Intalox (IMTP) packing.
Feed Temperature (C)	120	127	120
Distillate Temperature (C)	115	118	115
Bottoms Temperature (C)	196	200	186
Feed Pressure (barg)	0.7	0.7	0.7
Distillate Pressure (barg)	0.6	0.6	0.6
Bottoms Pressure (barg)	0.9	0.9	0.9
Condenser Duty (kJ/s)	4,427	4,169	5,800
Reboiler Duty (kJ/s)			5,200

Column bottom and top pressures were specified to keep them the same as the hand calculations. One could specify the pressure drop in the column or the pressure drop per stage. Instead of specifying the pressure, one can also specify the quality of the feed and that of the streams exiting the column.

TABLE 3 Simulator results for alkylate splitter D-120 compared with hand calculations of Ulrich (from Appendix G-1).

Analysis Tool	**Simulation using Tray-to-Tray (TT) Approach**				**Ulrich hand calculations**
Source of Thermodynamic Data	Lee/Kessler/Plocker Equation			Chao-Seader Equation	Fugacity correction factors based on Lee/Kesler charts
Minimum Reflux Ratio					0.23
Actual Reflux Ratio	0.26	0.084	0.044	0.226	0.3
Control or Specified Variable	Number of ideal stages = 17				Actual reflux ratio = 0.3
Minimum Theoretical Stages					5.2
Actual Theoretical Stages	17	17	17	17	16.7
Number of Theoretical Stages above Feed	13	10	8	13	
Tower Specifications					22 meter vertical tower, 2.2 meters in diameter, packed with 19 meters of 70 mm stainless steel metal Intalox (IMTP) packing.
Feed Temperature (C)	120	120	120	120	120
Distillate Temperature (C)	115	115	115	118	115
Bottoms Temperature (C)	207	210	210	212	186
Feed Pressure (barg)	0.7	0.7	0.7	0.7	0.7
Distillate Pressure (barg)	0.6	0.6	0.6	0.6	0.6
Bottoms Pressure (barg)	0.9	0.9	0.9	0.9	0.9
Condenser Duty (kJ/s)	5,595	4,817	4,647	5,464	5,800
Reboiler Duty (kJ/s)	5821	5052	4881	5819	5,200

This dialogue illustrates the power and the weakness of current simulation technology. Based on similarities in the first two columns in Table 3, for example, the ideal gas assumption evidently yields a valid result. Knowing this would have saved me countless hours of work evaluating fugacity correction factors.[8]

I was disappointed with flowsheet/streamchart documents produced by the software. We were both troubled by lack of "transparency" in the computer output. Results were distributed awkwardly throughout fourteen pages of printout.[9] It was clear to both of us that a designer must own the flowsheeting skills described in Chapter 3 to solve this problem, with or without simulation software.

[8]The validity of an ideal-gas model was not evident during calculation because, some correction factors were far from ideal (much different from one). Non-ideal component concentrations are apparently too small to be important.

[9] Beyond unhappiness with output format and lack of transparency, I am also critical of careless irregularities in units of measure in all simulation packages that we used. Even in SI mode, non-SI time units were typical, and pressure, whether gage or absolute, was ambiguous.

CHAPTER 5

EconExpert Software
Refer to page 363 of the text

Aklylate Splitter Module – Capital Cost Estimation
Refer to page 399 of the text

Cost Summary – Simulation Results

	N = 9 Cost in USD	Design Specs	N = 17 Cost in USD	Design Specs
Packed Tower	276400	2.286 m dia 9.6 m packing ht PP pall rings ** 345 kPa design pr 250 C design T	385300	2.286 m dia 19 m pack ht
Condenser	84500	118 m^2 – heat transfer area Tube length 6 m 25.4 mm out dia	86200	201 m^2
Condenser Accumulator	504600	672 m^3 Vol 6.4 m dia 20.9 m tangent to tangent length	504600	Same as previous
Reflux Pump	352400 *	1900 l/s flow	355600*	1920 l/s
Thermosiphon reboiler	116500	338 m^2 heat transfer area 6m tube length 25.4 mm out dia	119900	342 m^2
Total Project Cap Cost	4,006,174		4,240,942	
Total Operating Cost	2,668,450		2,752,567	
Total Utilities Cost	1,649,787		1,713,873	

* Error reported during execution of program – Specific gravity is out of range
** Did not find metal Intalox saddles

CHAPTER 10

Hazards and Risks (Refer to page 497 of the text)

My trip when returning from SACHE Faculty Workshop 2000[10] held in Wyandotte, Michigan began with an early morning taxi ride to the airport. Having just spent a week discussing **process** safety, I was attuned to that topic but hadn't thought much about **travel** safety until the cab ride.

Hazards involved in such a trip are many and consequences fearsome. Frequency depends on the weather, road and equipment condition, the driver, and extrinsic possible capricious events like falling trees, impact from another vehicle, etc. Frequency is, as we all know, very low. Hence, risk or the probability of a life-threatening event on such a trip is reassuringly small.

> I entered the cab at 5:15 am for an expected 15-minute ride to the airport. An automatic attempt to secure the shoulder/seat belt was unsuccessful. Like many cabs, the latch was hidden; lodged down behind and under the seat. (Consequences grew.) I gave up and drew the door closed, but the handle/arm-rest flopped in my hand, barely remaining attached. (That answered the question about equipment condition.)
>
> As he pulled away from the motel, the driver began a conversation, "You're my last rider. I started out 4:30 yesterday afternoon--been on duty for 13 hours. I've known some who've driven for 22 hours straight. The most I've been able to handle is 14."
>
> My thoughts went back to the harness latch. As we approached the freeway entrance, he asked, "Which way to the airport? Do you know? My mind kind of goes foggy at the end of a long shift." (The perceived frequency factor was rising rapidly.)
>
> Modeling after my wife's reaction when I get lost driving and need help,[11] I asked, "Why don't you radio the office? I've plenty of time." He agreed that was a good idea. Meanwhile, I resumed my frantic search for the harness latch.

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[10]Safety and Chemical Engineering Education workshop for faculty on Safety and Process Design (Sept. 17-20, 2000, Wyandotte, Michigan). Sponsored by BASF, AIChE Undergraduate Education Committee of CCPS (Center for Chemical Process Safety), Dow, Merck, Rohm & Haas, Shell, and U.S. Chemical Safety and Hazard Investigation Board; D. A. Crowl and J. Wehman workshop managers.

[11]"Why don't you stop and ask someone?"

> I was comforted by the authoritative, commanding voice from the dispatcher as she gave directions, and my search was successful. As I latched the harness buckle, I casually asked, "Have you stopped for coffee recently?"

The hazards of this taxi ride were no different from any other, except the condition of driver and equipment made the risk much greater. During the trip, I was able to reduce risk by securing the harness latch (lower consequence severity) and encouraging the driver to contact the dispatcher and pick up a cup of coffee (reduce accident probability).

Friction as a cause of fire
(Refer to page 507 of the text)

I remember seeing so-called "hot boxes" on passing rail cars as a youth. Wheel bearings lose lubrication, overheat, and throw sparks. I witnessed another friction-caused fire recently when a wheel fell from the axle of a boat trailer. Sparks generated by axle against pavement ignited dry weeds beside the highway and caused a life- and property-threatening inferno.

Danger All Around Us

An interesting safety incident occurred while I was writing this Chapter. It was early January, and I was walking from our Cambridge apartment to the subway station in Harvard Square. Being trash day, walks were partially obstructed in spots.

Passing along the narrow route between Longy School of Music and Cambridge Common, some pine boughs dropped on the shoulder of the man immediately ahead of me as he threaded his way between some trash barrels and an apartment building. I didn't pay much attention and followed right behind him. But hey, this was not the Maine woods! He stopped, looked back and upward. The expression on his face, caused me to do the same. There was an enormous Christmas tree in space at the fourth floor window, held by one arm. Just then, a voice said, "Is there anyone down there?"

I probably wouldn't have even bothered to look up if the guy in front of me had not stopped and exclaimed amazement. I tend to "ignore" a lot of things (the root for "ignorance"). That's the reason I would be a lousy safety engineer; not loud, nosey, or curious enough. As the personal safety incidents in this Chapter suggest, I'm also impatient and sometimes careless.

The problem with "Curious George" was not curiosity but impishness and stupidity. Curiosity combined with intelligence, care, and patience increases the probability that we and others will live longer healthier lives.

CHAPTER 12

REVISING, CUTTING, AND POLISHING

(Refer to page 547 of the text)

In 1991, my wife Laurel was awarded the Pulitzer Prize in History for her book *A Midwife's Tale*. During one of the celebrations, speaking with a group of friends, I discussed my role as reader and critic. I told how in reading one of the more difficult chapter drafts I became drowsy. When chided, I said, "Laurel, this reads like a novel. A Russian novel."

I told how she took that as an insult, muttering something about an engineer who didn't appreciate the fine points of scholarly writing. But soon the fuming ended, and she was back at the keyboard, spending days revising the chapter until it did keep me awake.

I contrasting our reactions to writing criticism, I concluded by telling our friends, "When Laurel criticizes my writing, I don't fall apart like she did, I just ignore it."

She fired back, "That's the reason I won a Pulitzer and you didn't!"

CRITICISMS OF STUDENT PROJECT REPORTS

(Refer to page 554 of the text)

1993 Project I–General Comments (Earlier year AIChE Competition Problem)

These reports were fairly well written, but even the best can be improved. In the past, I have given students a little pamphlet (*Take the Fog out of Writing*, by Gunning and Mueller) to read over Christmas break. It is a compact and powerful guide to more effective writing. I was too distracted with my own writing load to keep up the tradition last December but made up for it this week by ordering a new supply of pamphlets. When it arrives, I will put a copy in your box. All I ask is that you read it.

I saw evidence that flow sheets were not used effectively by all members of the group. It was as though the flow sheet came as an afterthought when the report was being written. Rather, it should be established early, and all members of the group should be working with copies of the same document and the same material balance numbers. Then, each time you meet, you can update and correct, so the final flow sheet is merely a cleaned-up version of what you have been working with. This way, material balances that don't really balance can be avoided.

Flow sheets violated a number of conventions defined in Chapter 3. Utilities were not designated adequately in most, for instance. There were many basic material balance errors or oversights. When I find that the numbers don't add up, I loose faith in the whole solution. (It's a sad comment, but I think students did better mass balances before spreadsheets were invented.) I think that it would be wise for all of you to reread the beginning twenty or so pages of Chapter 3 in the text. It will probably take less than half an hour, and it will pay off for the next report.

Most appendices could have been greatly improved. Tables, figures, and data tabulations were good, but it is not possible to check numbers unless the thread of sample calculations is continuous and complete. The most successful appendices include substantial written prose to explain what is happening. I saw evidence that computations were made by one person and read by no one else. There were a number of obvious errors that would have been picked up if there had been an independent check or proofreading. Also, be reminded that the *hour* is not a legitimate SI unit. Its failings should be obvious when one calculates power consumption for pumps, blowers and other motorized equipment.

We all need to improve our judgment and develop common sense. In heat exchangers, for instance, countercurrent flow is usually more appropriate than parallel flow. Some flow sheets in this batch of reports didn't acknowledge the difference. Some even had impossible delta temperatures. With a group of three or four educated chemical engineers, things like that should not pass uncontested into the report. I was disappointed that only one group bothered to compare their estimated selling price with the current ethanol selling price.

There were too many uncorrected trivial errors. You were not checking up on each other enough or, if so, not independently. Always do the rough numbers isolated from those you are checking. Then, compare the results and pursue discrepancies if they exist.

You could have been more creative and effective in your use of illustrations. All could have used flow sheets better to support the prose. I find it effective to have segments of the flow sheet included in the appendix or wherever calculations or procedures might benefit from an illustration. Such segments should have the same symbols, flags, numbers, etc. as are found in the flow sheet.

Figures should include explanatory legends that allow them to be understood in isolation from the text. If printed in "landscape" format, they should be bound with the top at the binding edge so the reader rotates the report clockwise to read it. This also means that the margin at the top (or at the left for "portrait" orientation) is wide enough that information is not hidden in the binding.

Appendices varied quite widely in quality and quantity in this group of reports. If quality is there, quantity will take care of itself. There were several instances of too much "chaff," pages of computer output or multiple pages of cash flow numbers. Such things can be handled effectively with one set of sample numbers or calculations and then a graph or plot to show trends and ranges.

I must say a word about "words." I have certain pet peeves. One of them, that doesn't necessarily apply to this project, is the word *particulate*. It was conceived as an adjective, not a noun. Thus, at least theoretically, the word *particulates* does not exist. One can properly speak of particulate matter but not particulates. Why not just say particle or particles? I have similar feelings about the word *cost*. I don't like its use as a verb even though, according to my dictionary, it's okay. Another example is the noun *size* used as a verb. One report assaulted my sensitivity doubly with the a statement saying some equipment was "sized and costed." I'm reminded of a computer guru who responded to the complaint that their jargon had polluted our language. "Any noun can be verbated," he wrote. (Not in this course, though.)

Now, my comments regarding individual reports:

Report 93-I-1

Early sections of this report were somewhat preoccupied with the wrong questions. They tended to focus on what you did and why you did it. Most crucial readers are more interested in how much the project will cost and what the ethanol selling price will be. These people will read and understand the Abstract and Summary. They will probably do neither for the balance of the report. The Summary did mention selling price but not capital cost. It was good, in the Summary, to identify the raw material cost as the overrinding economic parameter. Contrary to what you suggest, I doubt that much can be done about it. Investors are interested, nonetheless, in areas where important cost savings can be made.

The writing is quite wordy and, as a result "foggy." Work toward smaller words and more direct, smaller sentences. Sometimes statements are ambiguous. Examples that I observed are marked. The use of first person seemed excessive in this report. You might consider ways to neutralize that a little without adding extra words and dulling the impact.

I liked the equipment list. It could have been integrated more effectively with the text, however, rather than isolated at the back of the document. It was a good idea to add dryer vent gases directly to the stripper feed, making use of the energy without adding a heat exchanger.

I disagree with your proposal to use a flare rather than recover the vented ethanol. It represents a loss in potential sales of about $50,000 per year. The stream is too dilute to support combustion. Extra fuel would be necessary to maintain a successful flame. I also think the presence of a flare would convey a negative imager to the public regarding environmental responsibility.

I like the flow-sheet and material balance. The format is inviting, streams add up correctly, and good judgment prevails. Flow stream tagging and labeling were reasonably complete. There was, as with most flow sheets, some ambiguity regarding parallel versus counterflow in heat exchangers.

Sample calculations in the Appendix were quite easy to follow because of the running commentary. The reactor analysis seemed rigorous and correct, but it could have been done more elegantly, more simply, and just as accurately. I felt that the appendix would have been much more communicative if sketch segments conformed to the flow sheet. Each derivation involved different symbols.

The distillation analysis was well presented. It seems accurate, except for a discrepancy between R_{min} and the value of R where variable costs go to infinity. They should be one and the same reflux ratio. Equilibrium plots seem to be valid, but I would like to have seen actual data on the same diagram as the Wilson-derived curves to test whether the latter were reliable. One could compare the two by unbinding the report and overlaying the plots, but that shouldn't be necessary.

There was an erroneous ΔT in the last heat exchanger design. This joins an amazing list of misunderstandings regarding ΔT's, counterflow, parallel flow, phase change, and sensible heat found in all reports.

The dryer design was well done and well explained.

Report 93-I-2

Focus in the Abstract and Summary was good. Important results were identified and reported. One exception might be the sentence on MACRS depreciation, but you probably couldn't resist the temptation to show that you had found out what it means. The Introduction was well written, logical and interesting. The quality of communication would have been enhanced by integrating illustrations with the discussion. Several ideal opportunities to insert illustrations were missed. The general content of the report body was so well selected and outlined that I spent more red ink emphasizing writing style and its improvement. Note the overuse of one article "the." Note also editorial suggestions that shift expression from "passive' to "active" modes. You will agree, I believe, that it makes the writing more engaging.

Your sentences can be more compact, less wordy, more powerful. Organization of content and focus are excellent. Readers are told clearly what they need to know for effective decisions.

The flow sheet was quite good, although I prefer a more horizontal orientation. It was nice to see a material balance that actually balanced for the most part. There were some impossible heat exchanger arrangements and some questionable energy balances. The cost summary sheet seemed to be reasonably accurate, but the format was not the best for quality communication. There were too many digits, not rounded to meaningful levels, and no commas in the numbers. There was inadequate binding margin, no titles, no descriptive prose. The cash flow profile doesn't agree with the cost summary sheet. It shows $11+M investment compared with $5+M on the cost summary sheet. That is one of the first things an experienced person would notice and question.

More words in the Appendix would help smooth the rough edges. Illustrations were chosen wisely but not presented or described as well as they should have been. The illustrations were kind of isolated. In fact, I didn't find your McCabe-Thiele diagram until the end, in the back pocket. One section, eight pages of numbers in the Appendix, could have been replaced by your much more effective optimization plot. That figure, however, needs more descriptive notations. It is admirable that you obtained reliable vapor-liquid equilibrium data. The equilibrium plots represent a lot of effort and a valuable resource, but you didn't use them to their full potential to explain or support the distillation system design. I still don't understand your argument for dropping the stripping column. The reboiler energy balance was off. I was expecting to find an error there just from looking at the flow sheet/material balance. One of the group members could have done the same.

Report 93-I-3

The absence of page numbers is a serious limitation that I noticed right off with this report. There was a Table of Contents but no easy way find the items except by leafing through the report. The Abstract showed poor taste in its emphasis. It included an almost trivial item, the steam generator, in parallel with one of the most important items; total capital cost. On the other hand, selling price and other important aspects of the project were not mentioned. One needs to think carefully about what occupies a space as prominent and limited as the Abstract.

Much the same could be said about the Executive Summary. (Personally, I don't like the elitism suggested by using "executive" here, but that's neither here nor there.) This section was also out of focus. Investors and decision makers want to know costs, risks , strengths, weaknesses, and technical viability of the project, not the obvious restated.

I felt that the body of this report was an example of "fill-in-the-blanks writing." I didn't see much that was unique to your analysis. Readers want to know where to go with this project next. They need to judge your recommendations. You can help them to do this, but it doesn't seem appropriate to recommend a $3M project without blinking while emphasizing the savings involved with a $13,000 steam generator. (As noted in the report, I find that recommendation faulty, because you compare a one-time capital expense to annual savings, the old apples and oranges dilemma.)

At one point the estimated ethanol selling price is 47 cents per kg. At another, you quote 47 cents per liter. It may have been a typographical error, but it is a serious oversight that someone in the group should have picked up.

I like your list of assumptions, although it contains many items that should not be assumptions but the results of calculation and optimization. There is more meat in the list of assumptions than in the body of the report. In fact, you could have used that list to guide outlining and selection of emphasis for a more meaningful and useful document.

The flow sheet needs help. Note my general comments in the beginning of this document about rereading part of Chapter 3. Utilities were not specified carefully or adequately. The material balance table was unacceptable. Mass rates in unspecified units were mixed with molar rates, also in unspecified units, and in an indistinctive format. (If you are going to include molar rates, put them in parenthesis or brackets, so readers know the difference, and then explain with a key.) Balances around individual items of equipment didn't even jibe. Even the recycle spit did not add up. Mass was being created and destroyed all over the place.

I didn't see any real analysis of the reactor. Dryer calculations were excellent and clearly illustrated. That made it easy to find the major mistake which was ignoring latent heats. Hence, there was a large error in size estimation and steam consumption. The same problem existed with condenser design, but the procedure was clear. Flow sheet segments using proper conventions and inserted in the calculations serve as excellent illustrations. This requires a better flow sheet than you had, however. In general, the appendix was strong as a communication device, but weak technically.

The optimization was too cryptic to be useful. A prose description would have helped a great deal along with graphs and other illustrations. The computer output was indeed "chaff." See Chapter 9, page 409 of the textbook.

Accurate ethanol-water equilibrium data are critical to this analysis. Using ideal-liquid data invalidates the whole distillation analysis. The absorber analysis was like a hybrid distillation analysis with numerous confusing and distorted procedures.

This report was neatly presented, but technical content was weak. The economic analysis was better, however, and was well-presented.

Report 93-I-4

With no Table of Contents and limited page numbering, it is difficult to find one's way around in this report. The abstract seemed out of focus. Minor factors such as the byproduct credits for yeast and steam were given equal billing with selling price and capital costs. It turns out that the former are not so trivial in your analysis, but as pointed out in my comments, the steam credit is too large. Ironically, after making a big issue of these credits in the Abstract, you failed to deduct them on the cost summary sheet, so the manufacturing cost numbers did not include them.

The Summary was not the appropriate place for a process description. This would have been better placed later in the body of the report. Decision makers who read only the Summary are much more interested in selling price, capital cost, and other key investment questions. In this report, they would also be acutely concerned about your reservations concerning your solution and the cost and time of further analysis that you state (in the Letter of Transmittal) must yet be done.

The report was too general and vague with few concrete numbers, ideas and suggestions. Important findings were not clearly distinguished from the trivial ones. Most of my suggestions for improvement parallel the early pages of Chapter 9 in the textbook, and I recommend that you read that again.

Mixing of hours and seconds in the calculations drove me crazy. I recommend converting all data to SI before working with them (that means the *second* as the time unit) and then sticking with SI through the project. Somehow g/liter and g/hour were used interchangeably.

Calculations in the Appendix were difficult to follow. Prose should have been used as well as equations to guide the reader. Some of the detail might have been excluded, although the balance was not bad. Some pages in the Appendix were illegible. The reactor design derivation was lengthy, with more variables and manipulations than necessary. Even though this derivations could have been more elegant, the result seems to be all right.

The equipment cost estimate was seriously in error because of a failure to use realistic installation factors. Values of F_{BM} equal to 1.0 were found in several places. Another fishy result appeared with the dryer analysis. A higher credit was claimed for the low pressure energy-recovery steam than was paid for the original high pressure steam. This is a violation of the first law of economics (related to the first law of thermodynamics), "You can't get something for nothing."

Heat exchanger calculations were confused. Key variables such as $\Delta T_{(approach)}$, $\Delta T_{(passage)}$, and $\Delta T_{(log\text{-}mean)}$ were confused. There is no need to optimize exchangers if a rule-of-thumb optimum $\Delta T_{(approach)}$ is used.

The source of equilibrium data was not identified. Where did the Margules constants come from? How accurate are they? Over what composition range? Nonetheless, the McCabe-Thiele construction looked promising, until the rectifier was analyzed. There, the diagonal was used, by mistake, as the operating line, and the number of trays was much too small. There were several other errors in the distillation analysis as noted.

The flow sheet did not meet the standards outilined in Chapter 3. Utilities were not specified carefully or adequately. Temperature and pressure specifications were inadequate to support equipment design. Mass balances did not add up all over the place.

The optimization illustration was excellent. It showed creativity in its design, and it was easy to read and interpret. It could have been employed even more effectively if you had included it in the body of the report near the discussion of optimization.

The economic summary was weak. Readers need an equipment cost summary sheet to identify what the big-ticket items are. Byproduct credits were computed, but not subtracted in the cost summary sheet. The same happened with depreciation. In fact, the relationships among sales, total expenses, net profit, taxes, and net profit after taxes are all mixed up. There was no evidence of a discounted cash flow analysis.

1993 Project II--General Comments (1993 AIChE Competition Problem)

There is a tendency among all students to use too many significant figures. The numbers should be reported to the number of digits that have meaning. This is usually only three or fewer even though your calculators and spreadsheets give you many more. That was one advantage of the slide rule in the old days. We could only read numbers to three places. There were capital costs reported in these reports to nine significant figures. It is a sign of immaturity to use numbers this carelessly. Please don't embarrass our department by doing this in your next job.

Often, illustrations were not labeled as clearly and completely as they should have been. They would have profited from explanatory legends. Look at any good textbook for examples of how these tools are brought to bear in an explanation. Exploit your graphs, tables, and figures better.

You spent a lot of effort quibbling over items that had little impact on capital and operating costs while accepting without question almost 100 million dollars per year for quench nitrogen. It would seem obvious to look more seriously at recycle quench in this case.

Report 93-II-1

There were no page numbers in the table of contents. The abstract could have been more concrete by including some of the hard numbers that you reported in the summary and the body. The summary is intended to stand alone, so I usually write the rest of the report as though the summary were not part of it. The type quality was not the greatest, but that may reflect your economic status. In a real job, this should never be a limitation.

I noticed several places where dollars and dollars per year were mixed or confused. They are obviously much different and cannot be interchanged. The cost of quench nitrogen was a red flag in this analysis that should have prompted you to seriously consider recycle quench. It is admirable that you acknowledged and discussed this possibility, but the report was weakened by a lack of specifics.

I liked the flow sheet and the ease with which it could be consulted while reading the report, but the print was too small and dim. One shouldn't need to compromise readability for convenience. Arrowheads were missing on many of the flow lines. Given the emphasis in chapter 3, someone in the group should have corrected this. One glaring error shows on the steam generator with gas leaving at a lower temperature than the entering water. Mixed units found their way into the report. That is why I suggested never letting English units leave the problem statement.

The appendix was too random, lacking organization and focus. Too much extraneous material was included without selection and editing.

Report 93-II-2

This report was reasonably well written. It did miss, however, opportunities to approach certain questions such as, "Where are the major costs focused? Where are the areas of potential economic improvement? What are limitations in this result?"

I see some serious oversights in the cost summary sheet. There were no credits for byproduct steam and not expenses for oxygen and quench nitrogen.

The report showed progress in use of illustrations. A number of useful ones were included, but there is still quite a bit of room for improvement. You will notice that even the problem statement followed my advice on direction in which one rotates the page to read it. This report, on the other hand, still had those figures that were printed in landscape format bound backward. The illustrations were not labeled as clearly and completely as they should have been. They would have profited from explanatory legends.

There were mistakes or ambiguities with regard to heat exchangers. It's important to make the decision between tube-side and shell-side definitively and unambiguously. That is the reason a good heat exchanger symbol looks as it does in the text. You fell into the trap of an incorrect log-mean delta-T in the boiler where there was phase-change.

The appendix was balanced and easy to interpret, but more written text was needed to tie things together and aid the reader.

The compressibilities were seriously in error, but I couldn't find the backup calculations to point out the cause.

I felt that you did the problem as one might do a homework problem. You didn't go beyond the obvious. The high cost of quench nitrogen should have prompted a consideration of recycle quench. Other obvious expenses could have been revisited

Report 93-II-3

This was a comprehensive solution and a well-written report. Your optimism about the viability of this project was based on the way we compared this product in \$/kg or \$/std m^3. This, it turns out, was a poor choice on my part, but one that you and other groups should have rectified. It would be better to compare on the basis of \$/GJ, since this fuel has a lot of extra nitrogen. This would make it appear, incorrectly, to be better the more nitrogen that it contained. The high price of quench nitrogen is, in this analysis as in others, a serious concern; one that should have caused you to consider recycle more seriously. Your raw materials cost seemed high, but it included the quench nitrogen, which explains it. You should not have ignored utilities or steam credits, since we want the price of gas based on a free-standing plant, so that financial credit or blame is placed in the correct section of this complex. The appendix was exceptionally easy to read. your care with computations and units was admirable. Separation of water from nitrogen in the grinding loop is not as easy as implied in your analysis.

Report 93-II-4

In general, I thought the writing was balanced and clear. The abstract was too vague, however. Some readers who only see that section want to know the crucial specifics. Your comparison of alternate economics was complete and well-stated. The flow sheet was well done, and illustrations were clean and clear. You could have interspersed the illustrations with the text a little more effectively, I think. Your use of recycle gas for quenching was a good decision, and you did an excellent job of supporting it with alternate economic comparisons. Your equipment lists and cost summary were well done, wisely balanced, and easy to interpret. The conclusions and recommendations were well done. They represented considerable thought, and reflected quite well your analysis. The appendix was mixed. It could have been cleaned up and streamlined in spots with more descriptive prose. It could have been neater and more legible. Plots and other illustrations might have been employed to portray your calculations rather than numbers and equations in spots.

1995 Project II--General Comments (1995 AIChE Competition Problem)

While reading these reports, I found myself saying, "I would really like to work with this group on the next stage of the process, refining the flow sheet, correcting errors, refining recommendations." Of course, I would like it to be a real process with real promise..

To begin my general criticisms, I felt that most writers failed to use their flow sheets effectively. It was as though the flow sheet came as an afterthought when the report was being written. Flow sheets frequently violated conventions defined in Chapter 3. Often, for instance, utilities were not designated adequately. Other basic material balance errors or oversights were evident. The flow sheet/material balance should be established early, and all members of the group should be working with copies of the same document. Then, each time you meet, you can update and correct, so the final flow sheet is merely a cleaned-up version of what you have been working with all along. This way, impossible heat exchange situations and material balances that don't really balance can be avoided.

Energy budgeting was careless. Most of you have been indoctrinated on the value of energy, but it doesn't seem to be internalized yet. If you think of energy as money, <u>your money</u>, its impact might be more evident. There were numerous instances when energy was thrown around and wasted as though it had no value.

All beginning engineers need to improve judgment and develop more common sense. In heat exchangers, for instance, counter current flow is usually more appropriate than parallel flow. Some flow sheets in this batch of reports didn't acknowledge the difference. Some even had impossible delta temperatures.

There were too many uncorrected trivial errors. You were not checking up on each other enough or, if so, not independently. Always do the rough numbers isolated from those you are checking. Then, compare results and pursue discrepancies if they exist.

Prices of electricity and other utilities should change from case to case as fuel (natural gas) prices change. A real understanding of the basis for utility pricing would tell one to expect this.

All could have been more creative and effective with illustrations. Flow sheets, especially, should have been employed better to support the prose. I find it effective to have segments of the flow sheet included in the appendix or wherever calculations or procedures might benefit from an illustration. Such segments should, of course, use the same symbols, flags, numbers, etc. as are found in the main flow sheet.

Illustrations should include explanatory legends that allow them to be understood in isolation from the text. Figures and tables were often thrown into reports with no explanation. Legends should be used to clarify what's in the illustrations and help readers make sense of it all. If printed in "landscape" format, illustrations should be oriented with binding edge at the top so readers rotate the report clockwise to read it. This also means the margin should be wide enough that information is not hidden in the binding. Other careless details such as missing and upside down pages were noticed at times.

Perhaps, you'll be blessed with a Mac and some good software in your next job so you can put captions on illustrations and integrate text and graphics in a natural, meaningful way. I hope you also gain a machine with the ability to do subscripts and superscripts and control number formats. Then, you can avoid ridiculous significant figures and floating-point notation.

Appendices varied widely in quality and quantity. If quality is there, quantity will take care of itself. All appendices could have been improved markedly. Tables, figures, and data tabulations were good, but it is not possible to check results unless the thread of sample calculations is continuous. Most successful appendices included substantial written prose to explain what was happening. I saw evidence that computations were made by one person and read by no one else. A number of obvious errors could have been avoided if there had been independent checking or proofreading. There were several instances of too much "chaff," pages of computer output or multiple pages of cash flow numbers. Such information can be handled effectively with one set of sample numbers or calculations and then a graph or plot to show trends and ranges.

I must say a word about "pet peeve words." An example is the word *particulate*. It was conceived as an adjective, not a noun. Thus, at least theoretically, the word *particulates* does not exist, yet we find it in common use. One can properly speak of particulate matter but not particulates. Why not just say particle or particles? I have similar feelings about the word *cost*. I don't like its use as a verb even though, according to my dictionary, it's okay. Another example is the noun *size* used as a verb. One report assaulted my sensitivity doubly with the a statement saying some equipment was "sized and costed." I'm reminded of a computer guru who responded to the complaint that their jargon had polluted our language. "Any noun can be verbated," he wrote (tongue in cheek).

Quality of reproduction should always be considered when preparing documents. Readers tend to feel insulted if the page is unreadable.

Avoid overusing "the." We tend to use that word as a lazy way to begin sentences. As you reread reports, I think you will be surprised at how many sentences begin with "The." I suspect the same can be said of my writing. In general, eliminate unnecessary words. Write shorter sentences. Take the fog out. I am so convinced of the need for better writing that I have resolved to require seniors next year to buy the revised version of "Take the Fog Out of Business Writing" by Gunning and Mueller.

A good, experienced engineer in industry, seeing the economic frailties at the outset, may not have bothered to go through a detailed evaluation in the first place, suggesting, instead, that the client give up on this speculative technology. Developing that kind of judgment and confidence is of real value. It saves a lot of wasted engineering time and money.

This brings me to comments regarding individual reports. I include these with misgivings, because they are largely negative. My singing teacher carefully employs what she calls the three-to-one rule. Because singer's egos are so closely tied to their voices, she tries to provide at least three positive comments for each negative one. Otherwise, her students are devastated by criticism. Yet, as we all know, if you really care about a student's progress, you must provide negative correction.

As I wrote at the beginning, I would be delighted to work with any of you on the next stage of this project. You were reliable, hard working, and good natured through this challenging experience. You are a good class, and I think you will do well in your careers. Please multiply this praise by whatever it takes to satisfy the three-to-one rule, and proceed.

Report 95-II-1

The abstract and summary in this report were a little foggy, but its recommendations followed logically from the group's findings. You developed numbers and data that suggested this process offers no advantage over conventional technology. Based on this, you should probably have advised the client not to waste any more time or money on this one.

Your use of expanded methane as a coolant for subsequent gas clean up was creative and thoughtful. On the other hand, I thought that energy management of your syngas system was poor. With more thought, you should have been able to eliminate one of the distillation systems.

The report body got bogged down at one point with details and assumptions that would be better in the appendix. I worked on the fog index with a few sample paragraphs. It was pretty high in spots. Illustrations were well done, but they lacked context. You didn't use them in the discussion. They just stood out there all by themselves.

The flow sheet was well done except for stream data that were missing in critical spots and a few other problems as noted.

Conclusions and recommendations were flat. One problem was that you hinted at things throughout the report that should have been saved for the end to give more impact. Also, some powerful possibilities and implications of your analysis were never voiced. Observations about the lack of sensitivity of sales price to methane price were interesting. They could have gone further.

The appendix contained most of what could make it outstanding, but it wasn't blended very well. It was like making cinnamon rolls with all of the ingredients kept separate as I describe in chapter 12. There was not enough written description in the appendix. It was sketchy, without focus. Choose an important item and analyze it well. Then, summarize the analysis of similar equipment items in a table or graph. Next, choose another category and do the same. To use the appendix properly, the reader would need to do a lot of leafing back and forth. You should make that unnecessary. If you had organized the appendix better, I think it would have given you greater insight into the project.

Report 95-II-2

The text of this report was attractive and quite well organized. Reasonable judgment was shown in the way material was presented. The writing, however was wordy and needed reduction.

It was useful to have your comparison of various equipment fractions represented in plant capital. I was surprised that reactors and distillation equipment were not more prominent expenses. I have a hard time believing that CSTRs in series provide an optimum alternative, but I just couldn't find my way through your explanation or logic on the reactors. Illustrations and tables were pretty well done, but I didn't find them strategically located.

There was a serious oversight in the cash flow analysis. A_{CI} shouldn't vary for every year as it does in your analysis.

Discussion, conclusions, and recommendations sections were quite good. There was evidence that alternatives were explored. Important issues were raised and considered. They didn't go far enough in this direction, but it was a start. In contrast to some reports, you gave the reader a sense of direction and provided suggestions of where to go next. They caused readers to think more seriously and with more intelligence about the process. In real life, that would lead to a refined and improved version as the next draft. Some suggestions were trivial and much less important than others, however.

The appendix was not terribly effective. Pages were randomly organized with no real focus or clear thread of reasoning. Some calculations were difficult to read They should have been more compact. More written description and fewer numbers would have been welcomed in spots. Calculations and drawings were not neat.

The reactor analysis was either superficially done or poorly explained. It's hard for a reader to tell the difference. It was not done to my satisfaction. An appendix should be interesting, compelling reading to one interested in the project. I found yours lengthy and dull. The flow sheet had many flaws that I mention in my opening comments.

Report 95-II-3

The writing in this report was not coherent. A statement in the abstract about comparative pricing contradicted a similar statement in the summary. Ideas were organized randomly, with little focus. Each paragraph should have a topic sentence. Sentences that follow should have something to do with the topic. In this structure, I found sentences flitting from one idea to another. The effect, as I noted in the report, is like taking a walk through a parking lot where everything is about of equal importance. A good report is like a walk in the woods or on the seashore where we become focused in interesting things one at a time.

You allowed the laboratory data to impose impossible or impractical limitations on the design. Your liquid recycle rates were fantastic. These numbers were striking, like the flow of a river. Group members should certainly have checked those results more carefully.

The report body became bogged down with details, many of which should have been in the appendix. Final results were expressed more clearly and compactly. Conclusions and recommendations were focused better, but I found your closing, optimistic, sentence ("With a few changes, the selling price will probably fall within the market range.") hard to reconcile with your numbers.

Economic results were marred by serious errors that common sense should have caught. Installation factors for most equipment (other than package units) are usually at least three or greater. You reported several that were equal to one. The first cost summary sheet was inserted in my copy upside down. This proved to be symbolic. Byproduct credits, for example, were three times as great as raw materials and were of the wrong sign to be credits. Cooling water was the greatest single manufacturing expense. It just didn't make sense. Similar misunderstandings were evident in cash flow tabulations. There were a lot of unnecessary, repetitive spread sheet pages. These were especially tedious without any written explanation.

The appendix hard to work with. All tables, charts, and figures came first with no introductory or explanatory comments. These illustrations were nicely done, but their introduction was too abrupt, with no transition or help for the reader. When explanatory pages came, at the end of the appendix, they were quite good. If they had preceded tables and figures, some of the latter could have been used effectively to summarize a set of calculations. There were a number of serious technical errors (assuming compressors are isothermal, for example), but they were easy to find because the text was organized and clear. At this stage, the presentation was better than the engineering. The appendix fell apart, however, as sample calculations became unreadable and less coherent. One of the major concerns in this analysis was an enormous, unbelievably large recycle rate to the carbonylation reactor. I had hoped to be able to explore your analysis of this part of the plant, but I just couldn't read the pages clearly enough to figure out what you had done. Toward the end, the appendix degenerated to a lot of computational trials without interpretation. The flow sheet showed a lot of thought and work. It was coherent, no obvious major errors, but it was more convoluted and confusing than it should have been.

Report 95-II-4

Abstract and summary conclusions were abrupt and absolute. One should ask if there are conditions regarding the conclusions, possibilities that might have been overlooked. It is clear from your results that capital cost was the major culprit in this process. This should have been made more clear in the discussion. One wonders why this process should be so expensive compared with current technology. You should have cast some light on this.

Energy management in this design was poor. It seemed unwise to use fuel to preheat the synthesis gas feed when so much heat was available from process streams. The amount of fuel needed for preheat was severely overestimated also. You generated steam at 1 bara pressure which makes it at such a low temperature as to be almost unusable. Writing in the main body of the report was generally clear and understandable. The analysis failed to focus enough on the most important cost elements, however. Based on separation cost, one would look more carefully at the way you went about it to see if those costs can be reduced.

Comments about economics of this process were too vague and general. Not enough attention was paid to materials of construction since they had such a big impact. There were some serious errors in reactor designs and energy balances. I did not feel comfortable with your cost numbers because of obvious problems in your design.

The body of the report would benefit from more concrete information and illustration. Readers are forced to dig pertinent details out of the appendix. Speaking of the appendix, it was too much like a compilation of raw calculations; not enough descriptive text to move things along. It was too detailed and long.

Energy balances in general showed lack of common sense. Complex C_p equations were used, but they were applied at impossible temperatures (below absolute zero). More words were needed in the appendix and fewer numbers. There should have been more interpretation and explanation. Some pretty alarming capital costs were reported with little evidence of concern or comment.

The flow sheet was marginal. It had the appearance of an afterthought rather than a key document used frequently throughout the project. Many key items of information were missing or poorly presented.

Report 95-II-5

I found the body of this report too brief. The abstract was a two-sentence platitude. The summary was more like an abstract, and the rest of the body was about right for a summary. There were some excellent illustrations filed in the appendix that could have been used to flesh out this report. The text was well written and "tight," but, I felt that it was too tight. After reading the body, I still had some basic questions like, "What is the fixed capital?" "What are the most questionable or vulnerable economic results?" This project has a lot of interesting questions and possibilities that you didn't explore.

It was useful to note errors or oversights such as that regarding blower L-126, but somehow you overlooked the enormous logistical error of equating net annual profit to annual total expense. It was distressing to see so much time dedicated to nitty-gritty then have it obliterated by this mistake. It reminds me of the saying, "They strain at a gnat but swallow a camel." It suggested that you budgeted too little time for pulling things together in the report.

The flow sheet had many flaws that I mention in my opening comments. Tables in the appendix were neat and nicely done, but they should have followed explanatory and sample calculations instead of preceding them. As it was, many questions raised by tables were answered later. Sample supporting calculations were quite well done, especially those concerned with mass balances. Several illustrations were inadequately discussed. The upside down distillation equilibrium curve was one interesting example. I still don't understand the reaction-rate plot. Selection of construction materials is an important issue that was not explained or discussed. Design of carbonylation and hydrogenation reactors was inadequately documented. Problems or opportunities in dealing with the waste gas steam were ignored. Energy budgeting was careless and wasteful.

Report 95-II-6

I found the abstract and summary of this report interesting and well organized. I was critical, however, of a discrepancy between your findings and your recommendations. The difference between your price estimates and the market value of methanol was too great to justify the optimism of your recommendations.

In the report body, prose became tedious with extraneous detail and poor focus. Many statements of common knowledge could have been left unsaid. It began to remind me of some computer manuals where they repeat everything so much that the document becomes many times longer than it should be. It becomes hard to find the point. In this report, it became difficult to isolate the important from the trivial. It was foggy, too many words, long sentences, long, unnecessary words. The technical competence exhibited in this report was not served adequately by the writing.

The appendix, on the other hand, was superior. Sample calculations were easy to follow. Errors, which were few, were easy to find. I think the appendix would have been much better if the excellent summary tables had been interspersed with calculations, a table after each equipment category. The summary of assumptions was useful and well-done.

Some installation factors, F_{BM}, were 1.0 when they should have been larger. This was true of other reports also. If there is a problem of understanding, I suggest that you reread the introductory pages to chapter 5. Utility costs were high. More creative use of energy was called for. One doesn't cool a 700^{o}C process stream, for example, with cooling water. We can use it for preheating or steam generation, at least.

Cost summaries and cash flow analyses appeared to be accurately done and were excellently presented. You should be more careful about reporting irrelevant significant figures, however. This report faded in the methanol synthesis-separation section of the plant. What was presented looked pretty reasonable, however.

Report 95-II-7

This was a well-organized report, and it was generally thoughtful. The abstract was a good, clear statement. On the other hand, the summary was almost the same as the abstract, whereas it should be an amplification of the project with enough concrete information that decision makers can form their opinions without going any further. Such items as plant capital, alternatives, and recommendations for the next step might be included.

Writing was wordy and can certainly be streamlined. I found the reactor analysis sketchy and ambiguous. Supporting calculations did not really support your results. Using distillation after the second reactor is interesting, but I don't think that you need the purity designed for the overhead stream. Format for discussion and concluding sections was good, but choice of content was rather strange. Minor things received the same prominence as major items. There was no real sense of priority or importance. I couldn't figure out why ammonia refrigerant was used when cooling water would do as well. Readers need to be let in on the reasoning behind such a choice.

Coming face to face with unexplained tables and graphs in the appendix was an abrupt and unwelcome change. These illustrations would have served nicely to support various design discussions, but by themselves, they were not as useful. Much of the appendix was like a set of raw calculations. Readers need a map, not just data. Things got better later in the appendix.

Except for misplaced stream numbers and some missing data, the flow sheet was well done. Isothermal compression assumptions, double inclusion of auxiliary facilities, failure to use the six-tenths rule, are examples of some errors present. The reactor analysis remained much of a mystery with no clear explanation.

Report 95-II-8

Writing in this report lacked logic and coherence. A paragraph would begin with one sentence having one idea and then shift to another idea with the next sentence. As a result, it was difficult to grasp any meaning from the text. Estimated prices were considerably greater than market prices, yet the report still encouraged more work and research. It didn't make sense. It shows lack of faith in your own numbers. A more logical recommendation is to drop the project before more money is wasted on it.

The writing can be cleaned up considerably. Tenses do not agree. Plural and singular modes are mixed. Sentences are too long, including many unnecessary words. Too foggy.

It was useful to see a distribution of capital costs, showing compressors to represent 65%. Given this, one would expect a lot of attention focused on compression and energy recovery calculations. I could find none in the report. There were too many vague promises. Recommendations were overly optimistic given the data. It was like a snake-oil sales pitch.

The flow sheet was neat and easy to read. There were a number of discrepancies, however. The appendix was good in that explanatory text was given. Unfortunately, explanations were not clear, specific, or coherent.

Graphs and tables were nicely done, but they also didn't seen to fit in any logical context. There were no supporting calculations. It is an art and a skill to fit supporting calculations, written text, tables and graphs into a coherent, meaningful whole. It's the cinnamon roll analogy that I mention in chapter 12 of the text.

Cost summary sheets and capital cost summaries were good. The cash flow analysis ended up subtracting depreciation twice, so final numbers were even more optimistic than they should have been. The error in cash flow computations would wipe out any potential process improvements alluded to in the text. The overwhelming byproduct credit shown in the cost summary escaped mention anywhere else. That is a clear gnat versus camel problem. Also, electricity prices should change from case to case, because fuel prices (used to make electricity) change from case to case.

Report 95-II-9

This report showed a lot of work. My major criticisms concern judgment and focus. One of the first things I noticed was a discrepancy with cost trends and raw material prices. The deltas just didn't make sense. An experienced, perceptive reader would pick that up right away. This, in a way, is a compliment. You wrote concrete statements and reported specific results in a way that this kind of thing could be picked up easily.

Redundant statements, unnecessary verbiage, lack of focus, and foggy prose permeated the writing. It was hard, in both text and calculations, to figure out what was of most importance. You did not sort wheat from chaff. As a result, the report was long and boring. You had the basis for making it much shorter and more interesting. Most calculations were well done and complete. The next step, however, of sorting things out and coming up with the vital results was not there.

Illustrations were good, but they were not used to advantage. Just thrown in as a unit, their significance is hard to identify. Each illustration should have a purpose, and its purpose should be explained by the text that surrounds it.

The reactor optimization gave some ambiguous conclusions. Neither the optimization procedure nor the ambiguities were resolved to my satisfaction.

I was surprised at problems with the economic analysis. Most engineering calculations were done with care while major errors were made in cost summaries and cash flows. I didn't feel that conclusions and recommendations followed logically from this report's findings. Recommendations for future work were positive while conclusions about the economics were quite negative.

The appendix had some high points, but it was just too long, too detailed, and too flat. There was no effort to select and focus. At the end, it really became tedious, almost like reading a stock market report. It took a lot longer to read this report than it should have.

The flow sheet was well done, one of the best.

2002 Project I--General Comments (Problem 3-6 Automate Yellow 96 Production)

My wife always welcomes my grading of reports from the first design project. She knows that I would rather clean bathrooms and vacuum floors than read poorly-written reports. Her optimism was rewarded again this year. But as I was putting away the vacuum, I vowed that the second set of reports was going to be better. I have put together this critique in hopes that you will take my advice as students have in years past and deliver some superb results for the second round.

I write this with misgivings, because my comments are largely negative. My first singing teacher carefully employed what she called the three-to-one rule. Because singers' egos are so closely tied to their voices, she tried to provide at least three positive comments for each negative one. Otherwise, her students were devastated by criticism. Yet, as we all know, if you really care about a student's progress, you must provide negative correction.

You were, hard working, and good-natured through this challenging experience. You are a good class, and I think you will do well. Please multiply this praise by whatever it takes to satisfy the three-to-one rule, and proceed. As I asked of you, I have tried to avoid sarcasm, but I have been blunt, so please don't take offense.

I saw evidence that flow sheets were not used effectively by all members of the group. It was as though the flow sheet came as an afterthought when the report was being written. Rather, it should be established early, and all members of the group should be working with copies of the same document and the same material balance numbers. Then, each time you meet, you can update and correct, so the final flow sheet is merely a cleaned-up version of what you have been working with. This way, material balances that don't really balance can be avoided.

I was disappointed to find my flow sheet almost repeated identically in these reports. Had I known that would happen, I would not have made it available. I intended it as a template from which you could create your own process description. Instead, there was little creativity. In several cases, my imperfect version was made even worse. Mass balances didn't close, stream flows were ambiguous, and impossible temperatures and pressures were shown. Flow sheets violated a number of conventions defined in Chapter 3. There were many basic material balance errors or oversights. When I find the numbers don't add up, I loose faith in the whole solution. I think that it would be wise for all students to reread pages 25 through 44 in the text plus the supplementary materials handed out in class. It will probably take less than half an hour, and it will pay off for the next report.

Most appendices could have been greatly improved. It is not easy to check numbers unless the thread of sample calculations is continuous and complete. The most successful appendices include substantial written prose to explain what is happening. Writing is like composing a picture or a story. A good painter or author defines a plot and then develops it. No plot--no drama.

Appendices were high in quantity but low in quality. If quality is there, quantity will take care of itself. There were several instances of too much "chaff," pages of stuff that could be handled effectively with one set of sample numbers or calculations and then a graph or plot to show trends and ranges.

Appendices, flow sheets and report bodies, seemed to be solo jobs, as though one person composed and no one else read. All persons in the group are judged by one document. All reports had defects and errors that could have been corrected by independent checking and proofreading.

I've been through a lot of fog this week. I tried to show you how to dispel it by sample rewritings at various places. All students should read the small booklet *Take the Fog out of Writing*, by Gunning and Mueller, on reserve in the library. You should also reread Chapter 9 omitting, perhaps, the sample report beginning on page 413. Much of the red ink on your reports restates things that are said in Chapter 9.

All reports could have been more creative and effective in their use of illustrations. Rather than treat the flow sheet as an obligatory document, use it to support the prose. It doesn't need to be isolated in the appendix. It can serve as a basis for your process description. I often include segments of the flow sheet throughout a report to illustrate calculations. Such segments with the same symbols, flags, numbers, etc. as found in the flow sheet can provide powerful support for a procedure.

Several basic protocols of effective technical communication were ignored. Figures, for example, should include explanatory legends that allow them to be understood in isolation from the text. Pages, figures, and tables should be numbered. I believe more than half the sentences in this series of reports begin with the word "the." It's a lazy, cheap, boring, way to begin a thought. Think of more creative and lively ways to express your ideas and findings.

These reports betrayed how powerfully you have been conditioned by four years of homework. Projects were approached as though there is some preordained single solution that the teacher or boss knows. In real life engineering, that is not true. Sometimes the boss doesn't even understand the question fully. It's your job to define the project and come up with directions for the next step. If the definition is ambiguous, use what resources you have to pin the objective down. Then, come up with a definitive recommendation. In this set, conclusions and recommendations were fuzzy, foggy, and wimpy, often stating "the problem needs more study." After all of this time and effort (and money in the real world), no supervisor is going to be happy knowing no more about the next step than she or he new when the project was assigned.

Now, comments regarding individual reports:

Report 02-I-1

This report is heavy on words, light on original creative content; full of platitudes, generalities, hedging; heavy on opinion, light on substance. There is a wheat/chaff problem with a lot of information thrown in as a big bundle without prioritization or focus. Some pages were out of synch, and it was impossible to tell what was missing because there were no page numbers.

Each paragraph should have an objective that is implied by the topic sentence. Then subsequent sentences reinforce that objective. In this report, I was troubled by random, scattergun shifting of topics and flitting from detail to detail, even within sentences. A lot of detail that should have been organized in the appendix was placed in the body surrounded by verbiage.

Note my edited versions of some paragraphs. I think you will have to concede that I was able to decrease the number of words by 50 to 80% while increasing clarity. In fact, this experience prompted the following clarity equation that applies to other reports as well:

$$\frac{\text{new clarity}}{\text{old clarity}} = \frac{\text{old word count}}{\text{new word count}}$$

There were serious problems with the flow sheet not meeting Chapter 3 standards; ambiguous stream flow directions, arrows missing from lines, inappropriate mass flow units (moles and hours, for example), pumps that decrease pressure rather than increase it, streams not labeled or labeled incompletely, equipment names missing, equipment labels not at flow sheet margins. There was no label on the flow sheet itself to identify the type of process, batch or continuous.

Economic results showed almost $4M per year in cooling water and raw materials for continuous above batch. At $50 per cubic meter for cooling water, something is wrong with the utility price calculation. When half of the process cost is for cooling water and it is dramatically different for two comparable processes, someone in the group should become suspicious. Ditto when raw materials costs differ by a factor of 2 for comparable processes.

Report 02-I-2

Writing in this report is disjointed, especially in the Summary (see my comments on topic sentences and paragraphs above. I rewrote part of your material and printed it on the back of your report page to illustrate what I mean. I think it illustrates how writing can be revised to increase coherence and impact.

I thought the writing improved in the Introduction and discussion, although prose throughout the report was quite wordy. The equation above applies to this document as well as the previous report. Prose in general was windy and wordy. There is no need to reeducate readers on chemical engineering fundamentals before introducing each new point. It becomes an obstacle that dulls the point. This report had too many pages (unnumbered to boot) and too many words. Editing, cutting, restructuring, and focusing would yield a great improvement in quality of presentation with no loss of information.

The appendix needed a little more "show" and less "tell." Theory section was "tell"-- sample calculations "show." I think these sections could have been combined and integrated to give a more powerful, coherent single statement. Sample calculations needed a narrative and "plot" to give them more purpose and direction.

Report 02-I-3

The writing was fairly well organized but a little foggy and remote. It seemed detached from reality. I think a little first person and active rather than passive verbs would liven it up. There was a tendency to throw in redundant or extraneous detail in the discussion, so the line of reasoning fades or is interrupted. Don't state the obvious. Sentences within a paragraph tended to flit from one topic to another, and the argument looses focus. To solve this problem, do an outline before writing. To detect it, extract an outline from what you have already written, and you will see the digressions and side tracks.

The appendix was neat and easy to follow, but it was incomplete. There were no back-up calculations for manufacturing costs, for example. In fact, I sensed some rehashing of my calculations that were placed on reserve.

Report 02-I-4

Many comments made above apply to this report; overuse of "the" to start sentences; garbled organization; unconnected thoughts expressed in the same paragraph. It needed a good outline. There wasn't much evidence of going beyond my material balance and flow sheet. Conclusions were vague and not creative. Claims of greater safety for semi-batch were made but without clear supporting arguments.

How do relative costs vary as capacity changes for the two processes? What are the major factors that favor continuous over batch or visa versa?

The continuous flow sheet doesn't work. Some streams go nowhere and material balances don't jibe. Junctions with two streams entering and two leaving show no way to control the relative flow rates. Pressures were missing and they didn't drop in the flow direction as they must without a pump present.

Many item capital costs were the same for both batch and continuous. That can't be true. Pumps should be much smaller for continuous, because the average flow rate is smaller. There didn't really seem to be any back-up design calculations for the continuous process.

2002 Project II--General Comments (2002 AIChE Competition Problem)

Thanks for improved writing in these reports. They were more interesting than the first set. Less work got done around the house while I was grading them.

If you think writing criticism ends with graduation, don't. While grading these reports, I underwent the trauma of receiving another set of reviewers' comments on the book manuscript plus my wife's harsh editing of the safety chapter. It's natural to be defensive about our writing, but when stung by writing criticism, it's best to move on to another round of revising and polishing. You are all young enough to enroll in a creative writing class, one of the best things I ever did--one of the best things you can do for future career success.

I still saw too much fog this past week. If you haven't read Gunning and Kallan's booklet *Take the Fog out of Business Writing*, you should grab a copy from Amazon and do so. Also, as with the last reports, much of the red ink left by me restates things that are said in Chapter 12.

From my general perspective, several possibilities for saving capital came to mind. First, it is clear that minimum capital is obtained by shortening cycle time and reducing idle capacity. For example, it makes a lot of sense to do the catalyst preparation and water-removal in a small separate jacketed vessel. This means the main reactor need not be jacketed and catalyst preparation/water removal can be done simultaneously with reaction. In other words, we prepare the catalyst for the next batch in this separate vessel while the current batch is reacting. As a consequence, drying time can be as long as reaction time with no penalty and the drying system can be smaller without extending overall cycle time.

Again, to keep things small, it might make sense to use a catch tank and let it serve as a place where oxide level is reduced to less than one percent. If the reaction is almost finished, there is no need for another safety overflow, and heat effects will be small, so the mixture might be pumped through the heat exchanger to the catch tank at a temperature that will prevent this adiabatic final cook from exceeding temperature limits. This will free the reactor for turnaround during which no overflow safety capacity is required. It also assures that the catch tank will be well-maintained.

For reasons of economy and safety, I would go for reactor operation near the maximum allowed temperature. This maximum is not a safety limit but a product quality maximum. Thus, in the event of cooling water failure or some other unplanned event, there may be overheating, but so long as the PO concentration is not too high, the overheating can be contained safely within the reactor. Safety will not be compromised. A batch will be wasted, but such a failure should be rare. Meanwhile, with operation at maximum temperature, batch time will be short, and reactor size small. This minimizes capital cost and satisfies the "intensification" criterion of inherently safer predesign.

I must admit disappointment with the problem statement. You were essentially force-fed and required to swallow information that was sometimes wrong or already half-digested. For example, it's insulting to tell chemical engineering seniors how to calculate heat exchange ΔTs. Also, heat capacities given for polymer in this problem are obviously too great. In fact, an important element of all design is defining the thermal and physical properties. Using the problem statement's heat capacity is especially onerous in this case because it leads to an underestimate of the potential for reactor overheating. Reactor contents will absorb only about half the heat of reaction predicted by use of these data. This is a clear example of how design error can lead to an unsafe situation.

It's counter to our educational purpose to give you incorrect data and force you to use it. I have the same feelings, of course, about units. It's been 25 years since AIChE officially adopted SI. I wonder how many more years before the AIChE problem committee allows contestants to use it.

The recommended capital cost approach is also highly flawed. Use of traditional Lang factors is ok when purchase prices are for carbon steel equipment but not for stainless steel. Reasons for this are explained in Chapter 5 where I develop the installation factor concept. Also treating all vessels equally as this statement seems to do is erroneous. Jacketed vessels will obviously be more expensive than bullet tanks. There is also the question of where to go for agitator costs if one is limited to the problem statement's data.

I was troubled by the statement's spoon-fed reactor design equations--essentially telling you to accept on faith something that you can and should derive on your own. These equations were based on traditional units from a lousy tradition. True, basic kinetic information might be given to us by the laboratory in awkward units as it was here. But, a good designer will take that information convert it to a theoretically and intuitively-satisfying form, then use it to derive the reactor design equation from scratch.

The statement's canned reactor design equation does seem to be correct when interpreted properly. Its energy balance, however, is not. Heat absorption by cold PO feed is not considered. Anyone deriving an energy balance from scratch would have detected this error and gained more of my respect at the same time.

Relying on someone else's derivation is bad design practice. Most of my major career contributions both in business and to the theoretical literature have occurred because I refused to accept old approaches without question. By deriving or re-deriving from scratch, I have improved or corrected past theories and practices or found better ones. You should always do the same. Otherwise, your job can be and eventually will be done by a machine.

Reports were more creative and effective in their use of illustrations this time. Flow sheets were used to support the prose, and segments of the flow sheet were used effectively in some reports to illustrate calculations.

Figures generally included legends, and most pages, figures, and tables were numbered. I believe fewer than half the sentences in this series began with "the," our lazy, cheap, boring, default way to begin a thought.

As with the first report, most appendices could have been greatly improved. It is not easy to check numbers unless the thread of sample calculations is continuous and complete. The most successful appendices included written prose interspersed with numerical examples to explain what was happening.

We could have saved some trees by excluding MSDS pages from reports. Yes, because of guidelines, they had to be in the competition submissions, and yes, they should be in the files of the designer. But, with so much chaff, it's difficult for a reader to find the wheat. Actually, only highlights pertinent to the project need be included.

No one really thought much about emissions. Purge nitrogen, for instance, has to go somewhere, and it will be contaminated.

Now, comments regarding individual reports:

Report 02-II-1

A hand-drawn flow sheet is fine for our purposes, but it should meet the standards of Chapter 3 (i.e., arrows at all junctions, relative elevations near actual, names and numbers of equipment at margins, raw materials entering left, products exiting right, etc). Something is wrong with the enormous flow of nitrogen that enters the process but doesn't leave. Also, the mass of water leaving is greater than possible from the KOH available. Otherwise, the mass balance is reasonable.

Absence of page numbers was a problem.

Three reactors with staggered operation might offer some advantages if scheduled so that cleaning and water removal is distributed over the cycle to use labor and auxiliary equipment more effectively. In this scheme, the Gantt chart shows cleanings overlapping, so this labor-intensive operation occurs simultaneously in the three vessels. If reactor start/stop times were distributed more uniformly through the cycle, they wouldn't overlap, and operators could be used more efficiently.

I found the Equipment Cost Summary sheet of the Appendix useful, but it appeared prematurely before sample calculations. This appendix was on the verge of being really good. To get there, verbal descriptions of each type of equipment design should have contained an illustrative numerical calculation for one item of equipment in that category. This could then be followed by the cost calculation. Then, tabulated results (design parameters) and costs found in the appropriate sub table on the separate Equipment Cost Sheet. This sequence; verbal description and sample calculation followed by sub table would then be repeated for each equipment type. Total plant cost would be assembled last. Most of the numbers were there. As demonstrated by my red ink, there were errors, and it took too much work on my part to find them.

Kinetic analysis and energy balance done with the same kind of care and sample numbers combined with your spreadsheet and verbal description would have been smashingly effective.

Report 02-II-2

This report was well presented. Pertinent and important aspects of the analysis were right up front in the Abstract and Summary. Like most writing, however, this document would have been improved by streamlining, editing, and cutting the prose. Based on

$$\frac{\text{new clarity}}{\text{old clarity}} = \frac{\text{old word count}}{\text{new word count}}$$

I see an easy gain of 30% clarity with a 30% reduction in words.

Writing was even better in the reactor design derivation, an excellent clear development of crucial equations. The energy balance would have profited from the same kind of methodical approach. Your transparency of design and important decisions made technical criticism and error detection easy.

Don't report every number to 8 or so significant figures is infuriating. Life is too short. Think the hours, days, weeks consumed writing down meaningless numbers. Rounding serves another valuable purpose. It forces one to define the accuracy to which a number is really known.

You invested too much faith in Polymath or whoever was programming Polymath. Results don't make total sense as marked in the report. Documentation was too sparse to find the problem. Otherwise, the documentation and derivations were interesting and rewarding to evaluate.

Report 02-II-3

The most serious technical error in this report was probably a major mass balance error stemming from an assumption of one K+ per polymer molecule. Otherwise, reporting contained too many words. Nitty-gritty trivial detail makes reader feel like a two-year old. Searching for the important in a vast sea of words is frustrating.

No real scientific basis for 2-reactor sequence chosen. Report argues that it satisfies Kletz's rule (minimization) of inherently safer design. But, the total amount of hazardous material is not reduced and by putting it in two vessels, Kletz's admonishment to *simplify* is violated. The result is greater expense and more seals to leak and instruments to fail. In essence, your final choice was based on opinion and conjecture rather than economics and total safety. ("Optimum" was used inaccurately to denote *safest*. In our context, that term implies the most *economic*.)

Appendix was poorly organized. Most of the effective useful documentation came near the end after pages of computer code, MSDS charts and other bulk. Put the most important material (i.e., mass balance calculations, reactor design analysis, etc.) up front where it is easy to find. Once found, calculations were reasonably well presented, so it was easy to isolate the source of mass balance error.

The safety analysis was deep but flawed. Being deep in some substances is not necessarily good.

Report 02-II-4

This report was fairly well written, although occasional redundant platitudes were thrown in, and the focus could be improved. Illustrative inserts in the text were well done and highly effective, in my opinion. You were creative in applying principles of ISPD to the reactor, but the concept of "intensification" was violated by having such large volumes. Choosing to react at such low temperature creates enormous volumes and increased hazard potential.

Economic considerations were given too low a priority in this report. Large reactor sizes and catch-tank costs make safety and other consideration irrelevant, because such an expensive plant would never be competitive. The overwhelming catch-tank costs deserved more attention. You might consider a single catch tank to serve all reactors which might be possible if reactor schedules were staggered. The idea of staggering the vacuum system was mentioned in the text but not manifest on the Gantt chart.

Linear extrapolation of vessel costs to large capacities in incorrect. Use the six-tenths rule, and extrapolate only within sizes commercially available. Reread Chapter 5 for more on this.

Equipment numbers and names were not consistent from the body to PFD to Gantt chart.

Batch size and mass balance calculations were not found in the appendix. This was a serious omission, because your large batch size was the major factor in excessive economics. Batch reaction time derivation was not documented. Again, this is critical to economics and safety. If there is an error here, you want it to be found. As it is, reader must accept your result on faith.