PROCESS SAFETY IN THE CURRICULUM

Explosion Prevention Technical Elective

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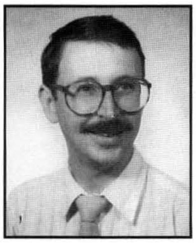
There are a number of good reasons to teach process safety to our students: we care about them and the community; to meet a need of industry; to reinforce basic concepts such as thermodynamics, reaction chemistry, and phase behavior; to illustrate the application of basic concepts to non-traditional situations; to add a practical aspect to the students' education, which is often lost in the rigor of derivations; to train students to understand the process chemistry and equipment, including the constraints of both; to fulfill ABET requirements; and, not unimportantly, because it is interesting!

This paper will explore what to teach, how to teach it, who should teach it, and when to teach it.

WHAT: TOPICS TO TEACH IN PROCESS SAFETY

Crowl and Louvar[1] cover the fundamentals of chemical process safety in their text. It includes the basic topics of toxicity, fire and explosions, ignition sources (*e.g.,* electrostatics), and more. Of course, each instructor will have his or her favorite topic, but in my mind the unifying concept is the reactive chemistry: a substance is toxic because it is reactive in our bodies; it burns because it reacts with an oxidizer; it is explosive because it burns rapidly and/or because it experiences a rapid chemical decomposition reaction.

Three measures to handle these reactions can be suggested. First, before a hazard can be addressed, it must be identified. Second, once a potential hazard is identified, the best approach is to prevent the reaction from occurring. Third, in those cases where complete prevention is impossible or not economically practical, the consequence of an incident should be minimized, that is, mitigated. Each of these three steps is discussed below.



Charles M. Sheppard *is Associate Professor of Chemical Engineering at Louisiana Tech University. He seeks to teach the upcoming generation of chemical engineers a design approach that includes hazard or safety awareness and environmental responsibility. His research includes two-phase flow implications to pressure relief device design, knowledge-based design systems, and fluidized catalytic cracker and other reactor modeling.*

Identification: Violent Reactions—Oxidation, Reduction, and Decomposition • The reactivity depends on the chemicals present and the energy in the system. Regarding the chemicals present, one can examine the type of chemicals (Bodurtha[2] lists twenty-one hazardous types of compounds, *e.g.,* azo compounds) or similarly, the structure of the compound (*e.g.,* reactive double and triple bonds). The chemical's structure can be found via chemistry books or through the web site

http://webbook.nist.gov/chemistry/

Thermodynamics can be used to calculate the energy associated with a reaction (*e.g.,* decomposition or oxidation). Some of the methods to perform these calculations include using available data and calculational tools (see Table 1), simulation packages, and the CHETAH program.[3] The CHETAH program allows the user to access data for many known compounds and to build other compounds. But even without the depth of the preliminary investigation indicated above, one can examine the reactivity of a system. This is illustrated in Table 2 for acrylonitrile production via the partial oxidation of propylene in the presence of ammonia. This table was constructed knowing the main reaction and considering all possible combinations of reactants. Possible chemical interaction based on the above chemistry reasoning and the experimental methods mentioned next, can be recorded for binary pairs on a chemical compatibility chart (see Table 3).

Regarding the effect of system energy on reactivity, one can begin by looking at the chemical state (see Table 4).

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Gases are generally more reactive than liquids or solids, and the higher the temperature the more reactive the system.

These two basic chemistry concepts of identifying possible reactions and quantifying the energy of the system based on the chemical state can go a long way to reduce the hazards associated with chemical processes. It behooves us to get the next generation of chemical engineers thinking in these terms.

Beyond these initial literature and analytical screening tools, any possible reactivity should be investigated via experiments. Table 5 (next page) lists some common methods going from the small sample size screening tools to the more detailed analysis tools requiring larger samples; more details are available in Reference 5.

Prevention: Attacking the Three Sides of the Triangle • The fire triangle (see Figure 1) teaches the requisites for combustion. By seeking to eliminate

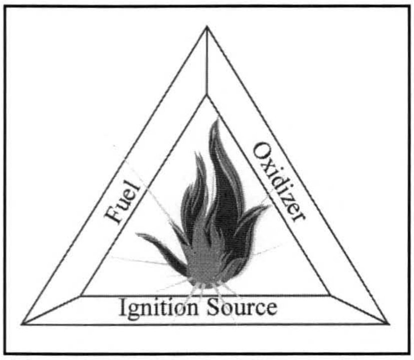

Figure 1. *Fire Triangle*

TABLE 1

Welker & Springer's *Safety, Health, and Loss Prevention in Chemical Processes* Problem 39: Thermodynamics: Constant Volume Gas Phase Reaction

Chemical Engineering Topic: Thermodynamics: Constant Volume Gas Phase Reaction

Safety and Health Concept: Explosions: Pressure rise for enclosed combustion reaction

Background: Refineries and chemical plants use a variety of low pressure vessels as knockout drums and seal drums. Most of these vessels are operated at very low pressures, but they may contain flammable mixtures of vapor and air. It is quite unlikely that ignition will occur in such a vessel because there is usually no source of ignition. However, there is always a chance that ignition might occur, so the American Petroleum Institute's Recommended Practice 521 (API RP 521), 1st edition, states; "Most knockout drums and seal drums will be operated at relative low pressures. To ensure safe conditions and sound construction, a minimum design pressure of 50 psig is suggested. A vessel with 50 psig design pressure should not rupture if an explosion occurs. Stiochiometric hydrocarbon-air mixtures can produce peak explosion pressures in the order of 7 to 8 times operating pressure, most flare seal drums operate in the range of 0 to 5 psig, and ASME code-allowable stresses are based on a safety factor of 4 to 1." Section 8, Division 1 of the ASME (American Society of Mechanical Engineers) pressure vessel code specifies a safety factor of four to one (applicable at low pressures only). That safety factor implies that a vessel with a stated mechanical design of 50 psig should not rupture at pressures up to 200 psig.

Problem: Show that the 50 psig design pressure suggested by API RP 521 will contain the explosive combustion of a mixture of air and n-hexane with initial conditions of 77°F (25°C) and 5 psig and stoichiometric concentration of n-hexane in air. Compare your result to the estimated pressure rise of "7 to 8 times operating pressure" referred to in the API standard. You may assume that the reaction proceeds to completion and that the products of combustion are carbon dioxide and water. (This problem was suggested by Mr. J.R. Phillips, a graduate student at the University of Arkansas.)

Extension to flammability limits

Look up the LFL and UFL. If you were to repeat the pressure calculations, under these conditions, how do you expect the results to compare? Which limit is more like reality? Perform the pressure calculation for this case.

TABLE 2

Chemical Reactivity Chart for Acrylonitrile

Reaction type	*Reactants*	*Expected Reaction (if any)*	*Endo- or Exo-thermic?*
main	propylene, oxygen & ammonia	Partial combustion	Exothermic
side	propylene	Polymerization	Exothermic
side	oxygen	None	-
side	ammonia	None	-
side	propylene & oxygen	Combustion	Exothermic
side	oxygen & ammonia	Combustion	Exothermic
side	propylene & ammonia	None	-
side	propylene, oxygen & ammonia	Combustion	Exothermic

TABLE 3

Chemical Compatibility Chart[4]

*Health**	*Fire**	*Reactivity**	*Component*	*propylene*	*ammonia*	*oxygen*
1	4	1	propylene	P	-	-
3	1	0	ammonia	0	-	-
0	0	0	oxygen	4	1	-

** NFPA (National Fire Protection Association) ratings: 0-hazard; 1-minimal; 2-caution; 3-danger; 4-extreme danger: P-polymerization or precipitation; X-unlikely mixture, S-special-minimal if dry, danger if wet.*

TABLE 4

Example of Safety Implications of Process Stream State and Contents[5,6]

	Case				
	a	*b*	*c*	*d*	*e*
Temperature	Medium	Medium	Low	Low	High
Pressure	Low	Low	High	High	High
State at Process Conditions	Gas	Liquid	Liquid	Liquid	Vapor
State at Ambient Conditions	Gas	Liquid	Vapor	Vapor	Vapor
Contents (e.g., fuel, oxidizer,...)	Inerts	Fuel	Fuel	Fuel; oxidizer	Fuel; oxidizer
Hazardous?	Minimal	Moderate	Significant*	Large	Extreme

**According to Welker[7] "low temperature liquid mixtures of fuel and oxidizers may be extremely hazardous. For example, liquid oxygen can form shock-sensitive mixtures with liquid fuels at very low temperatures. If the fuel and oxidizer are completely soluble, the mixtures can result in detonations.*

or shrink each side, we can reduce the probability of the occurrence of a fire or an explosion and perhaps the size of a fire if one does occur. Industry seeks to prevent the existence of flammable mixtures. Other examples are eliminating ignition sources, inert storage tanks, and reducing the amount of fuel present.

Inert gas can be added to dilute the flammable gas composition below the lower flammability limit. Calculating the amount or flowrate of inert gas required for safety reinforces the principles of partial pressure and revisits the concepts of a perfectly mixed tank versus plug flow.

Mitigating: Placement of Pressure-Relief Devices and of Equipment • "Mitigation" is reducing the severity of the consequences of an incident. Two common mitigation methods are including pressure relief devices and placing equipment strategically. The first seeks to eliminate or reduce the size of an explosion, and the second seeks to reduce the number of people and the amount of equipment affected by a fire or explosion. Pressure-relief devices are needed on the equipment that may be likely to be over pressure due to reaction, fire, compression, etc. Placement of the equipment should be such that fires and explosions that occur in one process area are not propagated to other process areas.

HOW: TEACHING THE MATERIAL

When approaching this topic, it is helpful to have a mix of experiments, demonstrations, and analytical theory. This mix both appeals to different learning styles and reinforces these valid approaches to problem solving. Table 6 gives some examples along with case studies illustrating that unfortunately these concepts are relevant to one's life expectancy as a process engineer.

The Louisiana Tech University chemistry department is very supportive in providing the demonstrations listed in Table 7. This demonstration time is always a favorite of the students. Of course, proper safety precautions should be followed, including but not limited to, safety glasses, hearing protection, and in some cases blast shields. One may consult the chemistry department at your school or Dr. Bill Deese at Louisiana Tech University for more details.

Text • I have found four potential texts for this course[1,2,5,8] They are all good, but have different strengths. Bodurtha's text[2] is specifically on explosion prevention and covers the basics well, but does not get into the chemistry in detail. Frank Bodurtha gave me permission to photocopy his text, now out of print. I believe if contacted in writing, he would grant others this same permission. I have used this book as a supplement both years I have taught the course. The first year I taught the course, AIChE had a special on Stull's

TABLE 5
Reactive Chemical Testing Equipment Choices

Tool	*Sample Size*	*Data Obtained*	*Conditions*
Mixing Calorimeter	2 drops-2 ml	ΔH of mixing or reaction	room temperature
DSC (Differential Scanning Calorimetry)	10 mg	exotherm or endotherm; Δ Hrxn, Cp, some rate data	temperature programming, no P data, no mixing, small sample (hard to obtain representative sample for heterogeneous systems)
DTA (Differential Thermal Analysis)	10 mg	exotherm onset	temperature programming, enthalphy change not quantified
RSST (Reactive System Screening Tool)	10 ml	dT/dt, dP/dt for a specific heat rate → vent size	temperature programming, no mixing, limited qualitative data
ARC (Accelerating Rate Calorimetry)	10 ml	dT/dt/ dP/dt, time to max rate Δ Hrxn, kinetic parameters	temperature programming, limited mixing (stir bar) mass of bomb absorbs energy, thus damping reaction rate
VSP (Vent Sizing Package)	100 ml	dT/dt, dP/dt with minimal energy loss, Δ Hrxn, flow regime, kinetic parameters	temperature programming, direct agitation, vessel venting and injection possible

TABLE 6
Process Safety Topic Covered via Experimental or Analytical Approach

*Experimental**	*Case Studies/Problem Sets*	*Analytical*
flammability limits	Flixborough, England	flammability limits (vapor pressure)
toxicity	Seveso, Italy	bond strength (-,=,≡)
	Bhopal, India	HAZOP
stoichiometry	Nitroaniline Sauget, Illinois	energy transfer rate
	Pasadena, Texas	polymerization
kinetics - ARC, VSP	Willey - Kinetics	energy of reaction Δ Hrxn
dust explosions	Welker & Springer	chemical compatibility chart CHETAH
burning speed	M&M	DOW F&EI
electrostatics experiments	Kletz - What went wrong	charge density and relaxation
Toluene water boiling point depression		liquid activity coefficient models

** Experimental indicates that either one can perform the experiments under carefully controlled conditions or that experimental data are available for analysis.*

monograph[8] for only $8. At that price the students could easily buy this text and the photocopy of Bodurtha's text. That year, the course had a very strong chemistry-of-reaction flavor. The sale was off by the second year I taught the course, so I opted for Crowl and Louvar's more general text.[1] It also is a good text on flammability, inerting, the DOW Fire & Explosion Index, etc., but lacks a strong reactive chemistry content. (We use this text in our first capstone design course that covers safety and economics.) I retained much of the strong chemistry foundation via my lectures and handouts. Finally, Barton & Rogers' text[5] is new to me. It is strong on the chemistry and the experimental method, but lacking the flammability limits and inerting. My current plans are to use this text next year, supplemented by either or both Bodurth, or Crowl and Louvar. The course text is greatly supplemented by the SACHE slides set, and the homework problems, discussed below.

TABLE 7
Flammability Demonstrations Provided by the Louisiana Tech University Chemistry Department

- Burning candle; illustrates the chemical reaction (burning) occurring in the gas phase with free radical reaction and radiant energy (from soot that will deposit on chalk put into the flame).
- Flame speed illustrated with an angle-iron channel and pentane flammable vapors.
- Flammable methane soap bubbles; gas density and energy and speed of rection-deflagration.
- Flammable hydrogen/oxygen soap bubbles; gas density and energy and speed of reaction-detonation. One ignites a handfull of the suds in a student's hands. (Safety goggles and ear protectors required of course.) It makes a loud bang but is safe.
- Flammable hydrogen balloon; gas density and energy and speed of reaction-deflagration.
- Flammable hydrogen/air balloon; gas density and energy and speed of reaction-detonation. (Safety goggles and ear protectors required, of course.)
- Carbon dioxide extinguishing a candle, illustrating gas density and oxygen requirement for burning.
- Dust explosion; ignition of dispersed Lycopodium powder in a closed paint can; lid is dislodged (to the ceiling) by the explosion.
- General chemistry concepts, including stoichiometry of reaction, pressure as a function of temperature, and excess fuel. One ignites rubbing alcohol (70% isopropyl) vapors in a 5-gallon glass water jug. Just after the flame, one puts his hand on the mouth and talks while the jug cools. The hand gets stuck to the jug as the pressure drops; then peel off the hand and air rushes in. Immediately thrust a burning splint into the mouth and ignite the vapors and remove the splint. A "ring of fire" forms and burns slowly from top to bottom of the jug.*

** Deese, W.C., "The Ring of Fire Demonstration," Chem. 13 News (November 1996). Currently, hazards associated with this demonstration, in addition to those discussed in the article, are being reviewed. Some have tried this with other alcohols, at higher temperatures and in oxygen-rich atmospheres with violent results. John Forman at Wright State University is currently performing a study using various alcohols with various amounts of water that bears on this demonstration.*

<u>Lectures and Homework</u> • Table 8 gives an outline of course content for the three-semester-credit hour course taught in a "quarter" system. This course applies knowledge the students have in chemistry, thermodynamics, and strengths of materials. We review actual incident case studies because "those who do not learn from history are bound to repeat it." One of the areas I desire to develop is in the experimental screening of potential reactions. At SACHE's 1996 Detroit meeting, Tom Hoefflich[9] gave some background on chemical screening via experimental measures. Braton and Rogers[5] present similar material and include information on both predictive (*e.g.,* CHETAH) and experimental (*e.g.,* Differential Scanning Calorimeter; DSC) approaches. The students use a DSC in the physical chemistry laboratory to find the heat of fusion for diphenylamine. Also, Ron Willey has several problems related to this concept in his kinetics problem set.

Table 9 (next page) gives a short list of potential homework problems. They are from the Crowl and Louvar text,[1]

TABLE 8
Course Outline for Explosion Prevention Technical Elective

Introduction (1) Crowl & Louvar, 1
1. **Definitions** (3) Crowl and Louvar 6; Bodurtha 3
    a. Fire triangle
    b. Oxidizing agent
    c. Explosion type
    d. Flammability limits flash point,LFL, UFL, MOC, etc.
    e. Flammability diagram, reading, and construction
2. **Chemistry of Combustion** (4 plus exam) Crowl and Louvar 6; Bodurtha 4,7; Stull
    a. Stability: possible reactions
    b. Thermodynamic measures
    c. Classification based on
        - Classes (Bodurtha, 7)
        - Chemical element present
        - Enthalpy of formation
        - Bond strength
    d. Measured kinetic reaction rate and activation energy (Seveso slides)
3. **Prevention and Mitigation of Fires and Explosions** (3) Crowl and Louvar 7 and 8; Bodurtha 5
    a. Inerting; below LFL or above UFL
    b. Ignition source (Crowl and Louvar 7; SACHE 1996 Workshop case study)
    c. Pressure relief (Crowl and Louvar 8 and 9)
    d. Inventory control and plant layout
4. **Case Studies** (3 plus presentation) Crowl and Louvar 1 and 13
    a. Flixborough (slides)
    b. Phillips (video and slides)
    c. ANGUS; Sterlington, LA
    d. Channelview, TX
    e. Students' presentations
5. **Identification and Quantification of the Risk** (2 plus final) Crowl and Louvar 10
    a. HAZOP studies (video)
    b. Using Dow's Fires and Explosions Index (Dow case study[16])

Welker and Springer[10] problem sets, Willey's[11-15] slide and problem sets, and original problems formulated based on thermodynamics concepts. One can choose from the available problems to emphasize the desired concepts.

Figure 2 shows the flammability diagram similar to one developed in the homework. This and other illustrations give representations from which the student can reason about the safety implication of leaks, loss of inert gas, and other incidents. The balanced combustion reaction in air (21% O_2 and 79% N_2) is

$$1\ C_3H_8 + 7\ O_2 + 26.3\ N_2 \rightarrow 3\ CO_2 + 4\ H_2O + 26.3\ N_2 \qquad (1)$$

The fuel composition is shown on the abscissa, the oxygen concentration on the ordinate, and the nitrogen composition is calculated as the one less these compositions (based on this ternary mixture and the mole fractions summing to one). The light grey in the figure shows the experimentally determined flammability region for propane and air. Also shown, in dark gray, is a calculated estimated flammability region. The lower flammability limit (LFL) is when just enough fuel is present so that it all reacts and combustion is sustained—fuel is the limiting reagent; the prediction is close. The upper flammability limit (UFL) is when enough fuel is present so that all the oxygen reacts and combustion is sustained—oxygen is the limiting reagent; the prediction is high but conservative. Below the minimum oxygen concentration (MOC), combustion cannot be sustained. This occurs with the minimum fuel composition and the stoichiometric amount of oxygen. Therefore, the MOC should be at the intersection of the LFL and the stoichiometric compostion line (having a slope of 7 O_2 to 1 fuel). Point F indicates a fuel concentration below which any combination with air (*e.g.,* from a leak) will produce a non-flammable mixture. That is, if a nitrogen purge keeps the vapor space in a tank to the left of the line segment between air and F, even if there is an air leak the resulting mixture will not be flammable.

Thermodynamics concepts like energy of compression, auto ignition temperature (AIT), and adiabatic flame temperature (AFT) tie directly into this course. The compression adds energy to the gas being compressed. The auto ignition temperature is the temperature at which a fuel in air can get enough energy from the environment to ignite. So if a gas is flammable and its auto ignition temperature (AIT) is exceeded, there is an explosion. This is what is believed to have happened in Channelview, Texas, in 1990, due to a faulty oxygen gauge during a compressor startup.[17] Shanley and Melhem[18] suggest that the AFT's do a reasonable job of predicting reactivity of compounds.

TABLE 9

Potential Homework Assignments for Explosion Prevention Technical Elective (both years included)

Crowl and Louvar (CL); Welker and Springer (WS); Bodurtha (B); Stull (S)

1.	Flammability	S; CL 1,6	CL 6-1,3; WS 41
2.	Flammability, AIT	CL 6, B 1-2	Constructing a flammability diagram CL 6-4-6 (LFL, UFL); Cl 6-10 (AIT)
3.	Explosions: Mechanical, Chemical	S; CL	Ideal gas; WS 14, 12, 34-39 etc.
4.	Prediction via ΔH_{comb}	S 1-2	CL 6-13; butane AFT; WS 37
5.	Chemical Classification	S	Assigned chemical MSDS
6.	Kinetics	S	Willey's Nitroaniline and Kinetics 18, 12
7.	Inerting and Pressure Relief	CL 7, 8	Willey's Seveso; CL 7-6,28; 8-2,9; 9-12
8.	HAZOP	CL 10	WS 46; CL 10-7,10
9.	Dow F&EI	CL; Dow F&EI[17]	In-class completion of Dow's workbook problems

An example problem from Welker and Springer[10] is shown in Table 1. It is based on applying thermodynamic concepts to the design of a knock-out drum. Part of the problem has been completed using a spreadsheet (see Tables 10, 11,12) and part is left for the reader. The problem can also be extended, as illustrated, to include other topics such as flammability limits.

WHO: STUDENT PARTICIPATION AND TEACHING

The students help teach the class. There are at least nine (see Table 13) multimedia presentations based on professionally prepared case studies. Each student presents a professionally prepared case study (see Table 14) and a presentation on the chemical process industry incident of their choice. The latter is prepared, along with a written report, toward the end of the course. One student had photographs from his grandfather of the Texas City fertilizer incident, which occurred after World War II, and

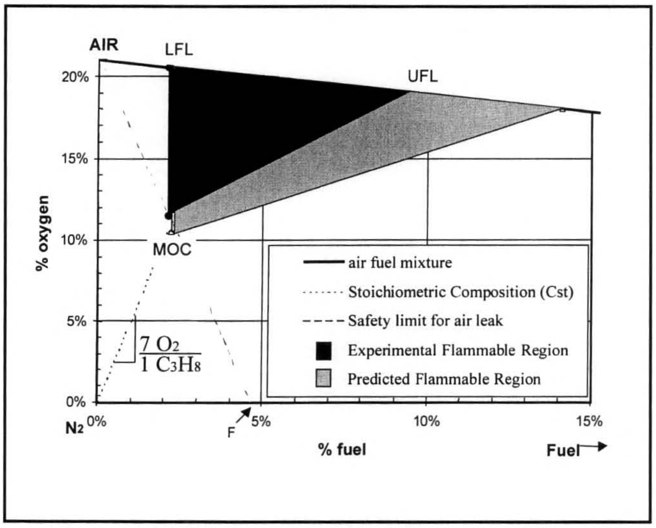

Figure 2. *Propane Flammability Diagram Constructed Using Excel (after Bodurtha[2]).*

which he researched and reported on. Another student researched the reactor explosion that occurred in her hometown of Lake Charles, Louisiana.

WHEN: CONCLUDING REMARKS

This course is offered to senior engineering and science students as a technical elective each fall. By this time the students have had thermodynamics, mass transfer, the first capstone design course, and are in reactor design. Thus, they have the needed background and their appetite has been whetted via the capstone design course. The class enrollment has grown with time, and representatives from local industry have provided positive feedback on the course.

ADDITIONAL MATERIALS

__Additional materials can be found on the following web sites:__

- http://www.chem.utah.edu/MSDS/msds.html • *(MSDS's)*
- http://www-portfolio.stanford.edu/no-form/100369/5 • *(Hazardous properties of materials: physical hazards, such as flammability and corrosivity; toxic effects such as carcinogenicity, toxicity, and target organ information; and regulatory requirements)*
- http://hazl.siri.org/ • *(MSDS's)*
- http://www.lanl.gov/Internal/organization/dx/DX2/dx2home.html • *(DX-2 high explosives science and technology)*
- http://ghg.ecn.purdue.edu/ • *(George Glob - Purdue LOX to ignite charcoal)*
- http://webbook.nist.gov/chemistry/ • *(structures and physical properties of chemicals)*

__The following slide/video sets are also available:__

- Bethea, R.M., *Phillips 66 Company Explosion and Fire at Pasadena, TX,* AIChE SACHE (1996)
- Bethea, R.M., *Process Safety Management with Case*

TABLE 10
Thermodynamic, Reaction, and Composition data for Welker and Springer 39

Compound	*Formula*	*ΔH form kJ/mol*	*Tmax*	*A*	*B*	*C*	*D*	*Coeff.*	*Conc. in Air*
Hexane	C6H14	-166,902	1,500	3.025	53.722	-16.791	0.000	1	0%
Oxygen	O2	0	-	-	-	-	-	9.5	21%
Nitrogen	N2	0	2,000	3.280	0.593	0.000	0.040	35.74	79%
Carbon dioxide	CO2	-393,509	2,000	5.457	1.045	0.000	-1.157	6	0%
Water vapor	H2O	-241,818	2,000	3.470	1.450	0.000	0.121	7	0%
Exhaust gas	xg	-	-	125.515	37.613	0.000	-4.665	-	-

TABLE 11
Final Temperature Calculation for Welker & Springer 39

ΔH rxn (J/mol)	3,886,878	=Hexane ΔH_form-CO2_coeff*CO2_ΔH–form-H2O coeff *H2O ΔH_form
Tin (K)	298.2	Given
Tout (K)	2,839.4	Calculated < Tmax?
ΔH process	0	ΔHrxn - ΔH sensible set = 0 by changing T_{out}
ΔH sensible	3,886,878	=(xg A*(Tout-Tin) + xg B/2*(Tout^2-Tin^2)/10^3-xg D* (1/Tout - 1/Tin)*10^5)*R_

TABLE 12
Pressure Calculations for Welker & Springer 39

P initial	5.0	psig	
P final	183.1	psig	=(P_initial+14.7)*Tout/Tin*SUM((N2_coeff):(H2O coeff))/ SUM((Hexane coeff):(N2_coeff))-14.7
P ratio	36.6	-	P_final / P_initial
P design	50.0	psig	Given
safety factor	4.0	-	-
P safe	200.0	psig	P design (safety factor)
P final<P safe	TRUE	-	= P final < P safe

TABLE 13
Student Presentations of SACHE Modules and Their Incident Research

Sept 3	Explosions slides
Sept 19	Miscellaneous case slides
Sept.24	Nitroaniline reactor slides
Sept 26	Seveso Dioxin release slide
Oct. 1	Dust, vapor explosions apparatus video
Oct. 3	DIERS/VSP video
Oct 8	Explosion control video
Oct 10	Flixborough slides
Oct 17	HAZOP slides, HAZOP video
Oct 22,24	Student report presentations

TABLE 14
Student Responsibilities for Slide/Video Presentations

- Get materials ahead of time and preview them
- For slide, read script and edit to make them clearer and more concise
- For both slides and video, prepare an introduction to orient the class and follow questions to reinforce key points
- Be prepared to answer questions

Studies: Flixborough (England), Pasadena (Texas), and Other Incidents, AIChE SACHE (1996)

- *Chevron Process Hazards Management* Video
- *HAZOP - A Team in Action,* Chevron Video
- *HAZOP - A Practical Element of Process Hazards Managements,* JBF and Amoco Video

<u>The following publications are available:</u>

- *SACHE Faculty Workshop: Characterization and Control of Chemical Process Hazards,* AIChE SACHE *(1996) (Electrostatics case study and experimental demonstrations)*
- *Dow's Fires and Explosions Index Hazard Classification Guide,* AIChE Publishers, New York, NY (1994)
- Goldfarb, A.S., G.R. Goldgraben, E.C. Herrick, R.P. Ouellette, and P.N. Cheremisinoff, *Organic Chemicals Manufacturing Hazards,* Ann Arbor Science (1981)
- *Guidelines for Evaluating the Characteristics of Vapor Clouds, Explosions, Flash Fires, and BLEVES,* CCPS/AIChE Publishers, New York, NY (1994)
- Kletz, T.A., *What Went Wrong? Case Histories of Process Plant Disasters,* Gulf Publishers (1988)
  21\. Lees, F.P., *Loss Prevention in the Process Industries,* Buttrworth-Heinemann (1980, 1996)
- *One Hundred Largest Losses: A Thirty Year Review of Property Damage Losses in the Hydrocarbon-Chemical Industries,* (Chicago: M&M Protection Consultants, 1986)
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The next major section of the book concentrates primarily on heuristics, both for operating conditions and design parameters. Much of this material is summarized in tabular form, providing students with a quick reference that they report was heavily used as they worked on their design projects.

In the third section of the book, the main focus is on getting the most out of existing processes and equipment. Again, there is a wealth of valuable information presented here, much of which cannot be found in other design texts. This material will probably find most use in a two-term design course, or in connection with some types of design projects.

The next section covers process synthesis and optimization, including heat integration (pinch technology), as well as use of process simulators. The chapter dealing with process simulation provides a particularly good introduction to this topic, emphasizing the need to start simple and warning of the various pitfalls students are likely to encounter.

The final section of the text deals with various other issues often covered in the design course, including ethics, safety and environmental issues, and communications (written and oral reports). This last material is especially noteworthy and includes a detailed report writing "case study" in which a report is critiqued and a checklist of common errors provided. This is by far the strongest and most detailed treatment of technical communications issues that I am aware of in a design textbook.

In addition to the costing data noted above, appendices also provide details needed in some of the examples and back-of-chapter problems, and present three design project pairs (one part of the pair a "grass roots" project, the other focusing on improvement of an existing facility). Additional design projects are available from the authors.

Perhaps more so than any other required course in the