SECOND EDITION

PROCESS DESIGN FOR RELIABLE OPERATIONS

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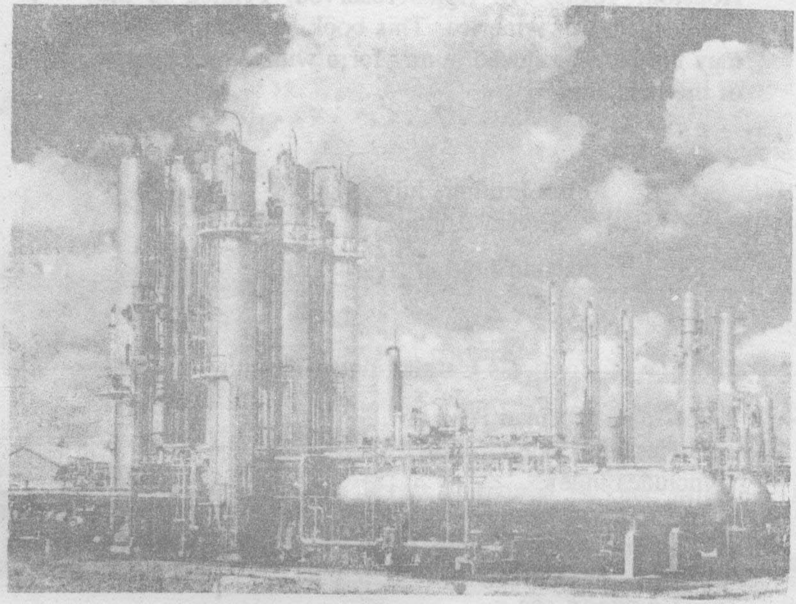

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Dedication

Life, Love, and Liz—
Such a sweet combination

Preface

Since the appearance of the first edition, I have presented many seminars to process engineers employed in the refinery industry. My interaction with the engineers attending these classes has prompted me to include in this second edition examples of designs gone awry.

Industry continues to lean more heavily on computerized calculations to produce process designs. Also, there is greater emphasis on standardized methods to specify reboilers, trays, flash drums, etc. These methods fail to recognize the unique nature of every process application.

Process engineering is more of an art than a science. A successful process design must consider the local climate, associated processes, variabilities of feedstocks, character of the unit operators, environmental constraints, as well as heat and material balance calculations.

If there is a moral in my book, it is to study and understand existing operations of similar process units before embarking on a new design. Inspect the equipment in the field, talk to the operators, examine operating data, and crawl through towers during turnarounds. If this is true for grass-roots facilities, it is even more vital for revamps.

I sometimes feel that I am the last representative of a dying art form. Certainly, computer technology has supplanted some of the intuitive engineering of my generation. However, the insight and creativity stimulated by intimate, hands-on knowledge of a process cannot be replaced by electronic gadgetry.

Finally, I would like to acknowledge Irene Lieberman, whose invaluable aid in organizing and typing this second edition cannot be overemphasized.

Norm Lieberman

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What Is a Process Design?

It was Pat's last day at work.

"Coal oil is produced at 350°F, steamboat oil at 550°F, and Foote's oil at 650°F." Chief Process Design Engineer Pat McNamara leaned back in his chair, brushed the sparce gray hair away from his wrinkled forehead, and prepared himself for a lengthy soliloquy.

Pat McNamara was, I imagine, the last process engineer to use the archaic terms of "coal oil" and "steamboat oil" for petroleum distillates. Pat is dead now, but his words and wisdom, honed to a fine sharpness by 40 years of practical process experience, still linger in my mind.

"A process design is more than just a summation of heat and material balance calculations. Because a process plant is more like a living organism than a machine, the process designer plays the part of creator, not just engineer."

Pat lit a large cigar, enveloped us all in a cloud of white smoke, and continued.

"A structure will either stand or fail, and is judged accordingly, but a process plant, like a man, is a collection of compromises, and hence can only approach perfection. The essence of a process design is its control strategy. It serves the same function in an operating plant that our central nervous system does in our bodies. Process plants each have a unique character which reflects the knowledge and experience of the man who designed their controls.

"Next to the control scheme, specification of the physical size of equipment is the most vital part of the process design. Typically, the inexperienced designer will oversize every part of the plant and then undersize an essential flash drum or pump, which then bottlenecks the entire operation.

"The process design specifies the size of such equipment as:

- ▶ Fractionator towers
- ▶ Flash drums
- ▶ Pumps
- ▶ Compressors
- ▶ Heat exchangers
- ▶ Vapor liquid separators
- ▶ Reactors
- ▶ Furnaces

"The relative arrangement of the equipment for maximum energy efficiency and capacity is another major function of a process design. Shall a particular pump be located upstream or downstream of a heat exchanger? Is it best to preflash crude prior to product fractionation? These are decisions for the process engineer to make.

"So you can see," Pat concluded, "a process design is really a plan of action, a blueprint, for the other engineering disciplines to follow."

"Then what," I asked, "are the major parts of the plant design which are not the responsibility of the process engineer?"

"Well," Pat answered, "the plot plan, or physical location of pumps, exchangers, towers, etc., is defined by the project engineer. Typically, he is a man with a civil or mechanical engineering degree; process designers almost always are chemical engineers. The project engineer will also size the diameter of the piping and determine the thickness of the vessel walls.

"The instrument engineer will have an electrical engineering background. He will make such important decisions as whether pneumatic (air) or electronic instrumentation will be used. Is it best to control a particular variable with closed-loop computer control, or have a man turning a gate valve in the field? This question is for the instrument engineer to decide.

"Working together, the process, project, and instrument engineers form the project team. This group eventually issues the plant's process & instrumentation diagram (P & ID).

"The P & ID is the fundamental document for building a process unit. Twenty years after a plant has been commissioned, the operators will still be consulting the original P & ID to solve operating problems. But the P & ID is based on the process flowsheet and that brings us back to the process engineer's job.

"Always remember that fallible humans operate a process plant, and the process flowsheet must reflect this weakness. The knowledge to compensate in the process design for human error comes only from years of field experience."

Pat McNamara swiveled 90° to face his beloved chalkboard, which was covered with the powdery remnants of some recent and perhaps final heat balance calculation.

At turns he would write a key word or phrase on the board, then expound on the point, and write something else. It went on that way for an hour.

It may have been his professorial manner, or perhaps it was my reflex as a former student, though to this day I still wonder why I began writing it all down so carefully. My notes follow.

The Elements of a Process Design Package

The model for a process design report is the UOP schedule "A" Package. UOP is a large engineering contractor and their schedule "A" Package is the industry standard for the components of a process design. It consists of:

- ▶ A process description.
- ▶ An overall unit material balance listing feeds and products.
- ▶ A process flowsheet showing major control loops.
- ▶ A listing of the composition (in mole percent) and quantity (in pounds per hour) of the major process streams. This listing is keyed to the process flowsheet.
- ▶ A line list giving the design viscosity, specific gravity, temperature, pressure, molecular weight and pounds per hour of every process and utility line.
- ▶ Heat exchanger data sheets.
- ▶ A listing of pumps giving the volume to be pumped, the vapor pressure of the fluid, and its specific gravity and viscosity.
- ▶ Fired heater data sheets, including vaporization curves.
- ▶ Vessel sketches showing all nozzle locations (but not necessarily sizes).
- ▶ Tray data sheets for fractionation towers.
- ▶ Compressor data showing suction and discharge conditions.

Process description. A simple written summary of the purpose of the plant and how it works. This part of the process design package should be written only after all the other components are assembled.

Overall material balance. The amount and physical properties of the plant's feed should be listed, along with expected product yields. All relevant properties of the products should be enumerated.

Process flowsheet. The most important document in a process design package—and frequently the only item that many people look at. A little bit of artistic drafting can be an aid to quick comprehension of the process by someone unfamiliar with the plant. Show control loops for clarity.

Composition summary. Provide a list of the mole-percent composition of every process stream. During the course of the process calculations, these data are developed and the process design package is the place to preserve it for future reference.

Line list. The flows in the line list need not coincide with the flows shown on the process flowsheet. The designer should anticipate that during start-up, a particular line may be required to carry twice its normal flow. Or perhaps during an emergency, a portion of the process may be exposed to unusually high viscosities. The line list is the place for the designer to make sure this insight is built into the plant.

Heat exchanger specifications. For each exchanger a standard TEMA heat exchanger data sheet is filled out. TEMA is the manufacturers' association which sets the standards for shell and tube heat exchangers. The heat-transfer inlet and outlet temperatures and viscosities are the main parameters set. Specification of the fouling factor is also an important, but nebulous, factor.

Pump data. Data tabulated will be used to select centrifugal pumps for each service. Using the maximum expected specific gravity, viscosity, and vapor pressure that can be anticipated for all occasions will result in a centrifugal pump being installed that will perform in adversity.

Fired heater data sheets. Since it is certainly the most costly item of equipment to operate in a process plant. The fired heater or furnace must be specified carefully. The designer sets the maximum allowable heat flux (in Btu/hr/ft^2), and this number, along with the heat duty (in Btu/hr), determines the size of the furnace. If vaporization will take place in the heater tubes, then a set of curves describing changes in fluid properties of the oil is required.

Vessel sketches. Trayed towers, reactors, and drums should each be defined by a vessel sketch showing the overall dimensions and distances between the centerlines of all nozzles. It is a good idea to note the locations of manways. You may one day have to crawl through a tower you designed. Details of process internals such as liquid distributors, as well as normal operating temperatures and pressures, are shown on the vessel sketch. The amounts and types of catalyst used are detailed on the reactor vessel sketches, as are the number and spacing of trays in fractionation towers.

Tray data sheets. Fractionation trays will be purchased from a vendor who will need to know the volumes and densities of vapor and liquid streams flowing through each tray of the tower. The designer also specifies the spacing between trays, and the type of tray (bubble cap, valve, sieve) to be employed.

Compressor data sheet. The suction pressure and temperature, the discharge pressure, the gas compressibility, and the ratio of specific heats must be detailed on the compressor data sheet. The discharge temperature is a function of the compressor efficiency and will be calculated by the manufacturer.

Pat fell silent. He toyed with his slide rule, yellowed with age, the numbered scales were illegible with wear. He dropped the ancient instrument in the desk drawer and shuffled his papers into an untidy pile. I left him sitting there; it was Pat's last day at work and we never spoke again.

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Packed Column Pitfalls

The metal rings lay in a disorderly pile across the road from the refinery manager's office. The manager, Mr. Hasselback, stared out of his window at the bent and crushed rings.

"You know," began Mr. Hasselback, "that tower ran fine for 16 years. Day after day we made on-spec gasoline, kerosene, and diesel oil. Then some engineer comes down here from Chicago and tells us that he can expand our crude running capacity by 20%."

Turning away from the depressing mass of twisted metal, Mr. Hasselback continued, "So that nut from Chicago tells us that we have to replace the trays in our crude tower with 3-inch metal rings. We pulled out 32 perfectly good, two-pass valve trays and replaced them with 6 sections of packing consisting of 3-inch perforated metal rings."

Warming to his subject, Mr. Hasselback's face flushed with anger. "We modified our crude tower internals exactly to the specifications of that crazy Yankee. He was right about one thing—we could run a lot more crude through our tower. The only trouble was that it no longer fractionated. We couldn't control our naphtha end point to make reformer feed, our kerosene didn't meet flash specifications, and our diesel oil contained so much gas oil that we couldn't sell it.

"Now packed crude columns may work fine up North," concluded Mr. Hasselback, "but here in Texas we need trayed towers. So you just go back to Chicago and tell the Vice-President to buy us a new set of valve trays for our crude unit."

I knew what had happened. The refinery operators had been careless during the crude unit start-up. They had allowed a pressure surge to develop (probably due to the sudden flashing and expansion of water to steam) and had upset the packed metal rings inside the tower. Trying not to look at the

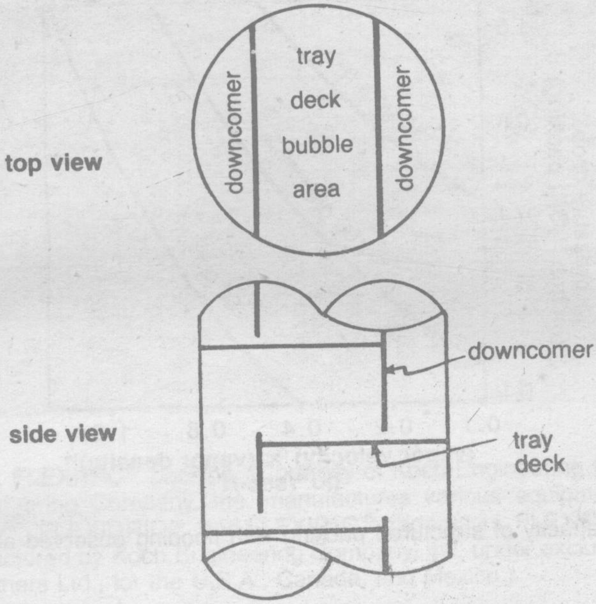

Figure 2-1. A large percentage of the tower cross-section is devoted to downcomers in a trayed column.

dirty mass of ruined metal rings piled across the road, I unfolded my drawings and began to explain the merits of packed versus trayed towers.

"Packing intrinsically has a greater capacity to handle vapor and liquid loads than a trayed tower. In a packed tower, vapor is the continuous phase, whereas in a trayed tower the liquid phase is continuous. To conduct liquid between trays, downcomers are required. As shown in Figure 2-1, typically 30% of the cross-sectional area of a tower is dedicated to downcomer area. For packed towers, the liquid simply trickles down over the packing.

"Without examining all the contradictory claims of manufacturers, but based on my design and operating experience, a properly designed packed tower can have 20-40% more capacity than a trayed tower with an equal number of fractionation stages.

Structured Packing

"Figure 2-2 shows capacity curves for one company's structured packing.[1] This material consists of mats of thin, corrugated, perforated metal sheets layered together in a vertical pattern. Field data obtained on several crude fractionation towers coincide with calculations made with these curves.

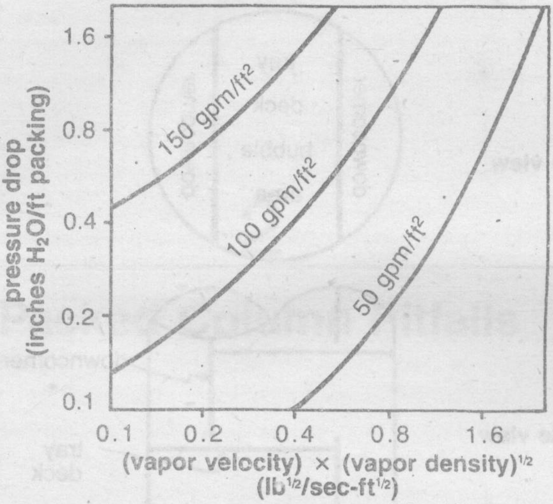

Figure 2-2. Capacity of structured packing with flooding observed at 2½" H_2O pressure drop.

"This company's structured packing may not be the optimum material available, but it does perform as predicted, both in regard to pressure drop and fractionation. Several other vendors sell competitive packings.

"For the example company's packing, a good rule of thumb for fractionation efficiency is:

- #2 packing provides one equilibrium fractionation stage for each 2½ feet of packing depth.
- #3 packing provides an equilibrium stage for each 3½ feet.
- #4 packing provides an equilibrium stage for each 4½ feet.

Rings Versus Structured Packing

"Structured packing is really the choice material to use in most refinery applications, although Cascade minirings® rings may be more cost effective than structured packing.

"A picture of structured packing is shown in Figure 2-3. The overriding advantage of structured packing is that it comes assembled in large sections (for example, two feet deep, four feet long, and two feet wide). Rings, on the other hand, are several inches in diameter and 1-3 inches high.

"A packed bed of rings is usually supported by a grid of flat iron bars (typically 3 inches high and ⅜ of an inch thick). The bars are set slightly closer together than the size of the rings being supported (see Figure 2-4). The rings are then covered with a chicken wire-type screen to hold them