

Process Engineering for a Small Planet

*How to Reuse, Re-Purpose, and
Retrofit Existing Process Equipment*

Norman P. Lieberman



A JOHN WILEY & SONS, INC., PUBLICATION

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*To the memory of shift foreman Mohamed Lee, born 2012–died 2090,
who shouted: “Shamil, you bloody fool! Throttle on the inlet guide
vanes to the blower; don’t open the discharge atmospheric vent.
Didn’t you read Lieberman’s book? You idiot! You’re wasting amps!”*

To my daughter, Irene, who assembled and reassembled this manuscript.

*To my wife, Liz, who inspired this project: “Norman! Stop whining about
the environment and do something. Maybe write a book.”*

*To my mother: “Your cousin’s coat is just like new. We’re poor people.
We have to get by with what we’ve got. You’ll wear the coat
and like it. And your aunt sent it especially for you.
Look, even all the buttons still match.”*

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Foreword

Mr. Lieberman's books, his knowledge and understanding of, and expertise in, the field are second to none. His writing is one of the best (if not the best) in the industry, unsurpassed for clarity, and at the same time absorbing and entertaining. You do not doze off reading his books. His hands-on approach makes his writing understandable by all and suitable for all levels, from the director and technical expert all the way to the novice and the nondegreed operator. People who have been in the game for decades will pick up his books and be able to gain new insights. His practical approach will make it possible for every reader to find something that she or he can use and apply immediately in their own fields.

This book represents a slight departure from Lieberman's normal writing. His writing usually teaches the practical art of chemical engineering and effectively passes on his vast experience to readers, preaching understanding and excellence in engineering. In this book, his teaching is supplemented with a message leading a crusade to "save Planet Earth from destruction, global warming, and environmental hazards." The beauty of this book is that he shows that following *good* chemical engineering practices paves a path to protecting the Earth. In contrast, he demonstrates how poor engineering and wasteful practices are one of the major hazards to our planet. He gets across the message: Protecting the Earth is not in "their" hands; it is not what "they" need to do. It is our responsibility as engineers. It is our duty to identify bad and wasteful engineering practices and stand up to them. Do not use the excuse that a manager above you set the tone. Do not hesitate to stand up to her or him. As a professional, fight such a person with good technical work. With his usual practical writing style and Lieberman humor, the author gets this powerful message across very clearly. Better than many of the politicians who talk about it, he is *doing* something about it. The political solutions that are promoted in the media often lack

a good engineering basis. The need is for engineering solutions, not political ones, and it is we who must come up with them.

There is no question that this book will be a great addition to the literature and is much needed by the industry. Unlike his other books, which are used primarily by industry, this book may make some inroads into academia. The “save the Earth” message will make it fashionable and popular, and academics frequently welcome new ideas, such as engineering rather than political solutions to our global warming problems. Lieberman’s usual audience of operation engineers, control engineers, process engineers, design engineers, process operators, and research engineers will be very interested—especially once the enormous costs and undertakings of carbon-capture technology are appreciated—and people will be seeking alternative cheaper solutions, such as those the author advocates. His message is universal and I believe will be supported almost unanimously by the process engineering community.

HENRY KISTER

FLUOR

Preface

Life goes on. And time goes on. The seasons change one into the other. The hills, the rivers, and the seas will survive, but perhaps without us.

It's a process problem. Our small planet, our home, is a rather large process plant responding to a number of process variables. One of these new process variables is man.

As I explained in my previous book, *Troubleshooting Process Plant Controls* (John Wiley, 2008), any unconstrained process variable may result in a **positive feedback loop**. Our human activities in the past 70 years have introduced just such an unconstrained variable into the dynamics of Earth's operation.

At the heart of the problem is the hydrocarbon refining and petrochemical processing industry—an industry that I, after 46 years of activity, have become identified with, owing to my design, teaching, writing, and field troubleshooting.

I can see in retrospect from the perspective of the process engineer that I have made a significant and sad contribution to the environmental positive feedback loop our little planet has entered. If our Earth is a complex *process facility*, it's clear that we can no longer escape the consequences of our actions. But how can we work to mitigate these consequences?

What's to be done? What can I and my co-workers in the hydrocarbon process industry do to retard environmental degradation? This book, *Process Engineering for a Small Planet*, focuses on this question. The text is basically technical. As in my other five books, the format includes stories drawn from my personal experiences in petroleum refineries, chemical plants, and natural gas production wells.

The lesson I teach is that we have to learn to use our existing plant facilities to expand production and improve energy efficiency rather than constructing new pumps, compressors, distillation towers, and vessels. The lesson is that we live on a small planet with limited air, water, and mineral resources. But rather than lecture

about morality, I have presented a series of technical and engineering examples to best fulfill my mother's advice: "Norman, we're poor people! We can't afford anything new. We've got to get by with what we have."

It's true! We live on a small planet. We've got to get by with the plant facilities we already have. This book will suggest how we in the hydrocarbon process industry can conform to mom's instructions.

For Whom Intended

Since 1983 I have been teaching a seminar entitled "Troubleshooting Process Operations." About 16,000 technical personnel have attended. In the last few years, I have devoted class time to detailing the growing environmental hazards—chiefly CO₂, methane, and NO_x emissions—that we, as process technicians, engineers, and managers, are generating.

The response to my challenge is the question: What's to be done? Engineers, operators, production personnel, and management in the hydrocarbon production and processing industry do not design solar panels, windmills, or fuel-efficient cars. We do not develop hydrogen fuel cells or methods to convert algae to biodiesel.

I am asked: "In the scope of our work as process plant personnel, what can we do?"

Process Engineering for a Small Planet is my response. What can we in the hydrocarbon process industry do to reduce environmental degradation? Can we contribute to the solution, or are we to be swept along by the tide of events?

We are surrounded by propaganda, which is misleading and often simply lies:

- Clean coal
- The hydrogen economy
- Ethanol as green fuel

Process engineers and operators do not need to look to exotic technology to make our contribution to combating the environmental crisis. Fully 10% of fossil fuels are consumed in the production, refining, and processing of coal, crude oil, and natural gas. Huge amounts of steel, copper, and cement are consumed to construct new, and often unnecessary, process equipment.

Process Engineering for a Small Planet is a handbook of ideas as to how to operate and retrofit existing process facilities to:

- Save energy.
- Reduce greenhouse gas emissions.
- Expand existing plant capacity but without installing new equipment.
- Reduce corrosion and equipment failures.

The text is technical. However, as in my other books:

- *Troubleshooting Refinery Processes*, 1980, PennWell

- *Troubleshooting Natural Gas Processing: Wellhead to Transmission*, 1985, PennWell
- *Process Design for Reliable Operations*, 2nd ed., 1989, Gulf
- *A Working Guide to Process Equipment*, 3rd ed., 2007, McGraw-Hill
- *Troubleshooting Process Plant Control*, 2008, Wiley
- *Troubleshooting Process Operations*, 4th ed., 2009, PennWell

the format includes stories drawn from personal experiences in petroleum refineries, petrochemical plants, and natural gas wells. The manuscript is devoid of complex mathematics and pedantic paragraphs. Technical text that is presented in a conversational tone is unusual, but *Troubleshooting Process Operations*, written in this style, has been on PennWell's best-seller list for 28 years.

Disclaimer

I have represented the technical facts in this book to the best of my understanding. However, references to places, names of refineries, and of individuals have been chosen at random. Any reference to people or places that corresponds to any actual people or places is purely a coincidence. However, all related experiences are technically complete and correct. Perhaps you will recognize one or more of these stories from your own experiences and think it is your story that I am writing—maybe it is and maybe it isn't. I have seen many of these scenarios in more than one place. As further evidence, in one of my seminars, an attendee came up to me on a break and asked who had given me his story to tell because the circumstances were so similar—it was not his story but it took a while to unravel the confusion. Please contact me if you have a similar question.

Engineering formulas presented here are usually approximations that have been simplified to promote comprehension at the expense of accuracy. References to more detailed texts are provided if accurate calculations are required.

The stories presented are stated in the context of my having initiated the improvements. Often, I was just a participant in implementing other people's concepts and have failed to assign appropriate credit. Such concepts have not been stolen from my clients—they have simply been borrowed and will be returned one day soon.

Process Problem Inquiries

If you have a process engineering question related to this or any of my other books, please call me at:

- 1-504-887-7714

Or, you may fax me at:

- 1-504-456-1835

There is no charge for such consultations. However, please don't send emails. I can't type and do not plan to start learning to do so at my advanced age.

Before you phone or fax, you would be best to conduct a field survey to collect the relevant data. While you are collecting the data in preparation for our phone consultation, you may well stumble across the bit of information that you lacked to solve the problem. Then you can forget about bothering me and thus avoid destroying my sense of peace and well-being. However, if you are absolutely determined to send me an email, my address is

- norm@lieberman-eng.com

NORMAN P. LIEBERMAN

May 2010

Introduction

Turning of the Tide

Morning had broken, like the first sunrise. The hidden fjord was bright and still in the sunshine. I paddled my red kayak easily between sheer rock walls cut by the strong hand of a long vanished glacier, toward the distant snow-capped peak. Space and time had lost all meaning.

Enclosed by the towering fjord, with no possible landing beach, I reversed course and headed back to camp. Paddling hard, I glanced at a tree growing from the cliff wall. The tree hadn't moved. In 20 minutes I had not progressed 20 feet. The tide had turned against me.

The tide would turn again, but then it would be night, which would bring a cross-wind and a rip-tide. Allowing the tide to sweep me farther into the fjord was an option with unknown consequences. Trapped in the fjord at midnight, with the black waves rebounding from the granite walls, was a fatal prospect.

What was I to do? I paddled with all my strength. Alone and afraid, I prayed for divine deliverance. But the Universe is vast, and the Creator did not answer my plea right away, but left me there awhile to think.

As a species we too are trapped, with time and tide turning against us. A tide of solar energy stored as carbon has carried us into a dead-ended technology. Oxidizing fossilized carbon to provide energy for 7 billion people in our growing industrialized economy is madness. Timing is uncertain, but the outcome can be calculated.

Like my experience in the misty fjords in Alaska, we'll have to rely on our own resources and with the tools at hand. Otherwise, the tide of greenhouse gas from

tar sands, shale oil, coal, peat, natural gas, methane hydrates, heavy crude oil, and nitrous oxides will sweep us into oblivion.

Some are waiting for new technology. Clean coal. CO₂ sequestration. Biodiesel from fermented cellulose. Some are waiting for Divine intervention. Others are hoping for offshore drilling. But I can't wait. Let's all face the truth. We must make progress with what we have at hand today.

The hydrocarbon process industry is at the center of the crisis. I just visited a coke gasification plant in Kansas. The plant converts petroleum coke to hydrogen. Great! Except that it vents 1 mol of CO₂ per mole of H₂. Suppose that this process becomes the long-term solution to the energy crisis in the United States? Tar sands, ethanol, shale oil, natural gas to liquids, fuel cells, the hydrogen economy—are all just as bad.

There are 10,000 to 20,000 senior leaders in the hydrocarbon processing industry. As far as tenure goes, I'm in the top rank: 45 years in refining, petrochemicals, and natural gas processing. Perhaps society as a whole cannot alter our carbon-dependent economy. But we, the process engineers in the hydrocarbon industry, can make a difference.

My book is not a solution. It's not even a plan, or a start, or the beginning. It's just a prayer whispered into the wind.

Let's use the process equipment that we have. Let's use our chemical engineering skills to avoid building new facilities, but operate our existing plants in an efficient manner. The expansionist economy we have created has to be reversed. How can this be done? Well, I've 45 years' worth of experience to share with you.

I paddled my kayak back for five hours and eventually won through. It was a struggle the whole way. Nor will it be easy for us to escape the mortal grip of the carbon economy that we, the process engineering community, have created. But I, for one, am going to try. This book is my contribution to that goal. If we don't try, we will surely fail. Ladies and gentlemen, the tide of time is not on our side.

Chapter *1*

Expanding Fractionator and Compressor Capacity

Last night, in my dreams, I traveled through time and space. The universe was vast: dark and still. In my dream I ascended Mount Olympus, where King Zeus, son of Cronus, Queen Hera, the Earth Mother, and Pallas Athena, Goddess of Wisdom, reign over the affairs of man and beast. Father Zeus and other immortals had gathered around a pool of crystal clean water. Peering into the pool, I could see images of my home, New Orleans, submerged beneath the waves of the Gulf of Mexico. King Zeus rippled the water with a wave of his hand. Now I could see Greenland, bare of its ice cap. Zeus waved his divine hand again and Kansas appeared. Not green with corn and soybeans, but as a desiccated windblown desert.

Athena, Goddess of Wisdom, looked sadly at me and said, “Thus have humankind’s actions destroyed the creation of the Titans; the Blue Planet; the Pearl of the Universe. Look deeply into the sacred waters and learn the folly of human ways.”

And as I obeyed the command of the daughter of Zeus, I saw a six-drum delayed coker in Los Angeles. Father Zeus spoke thus: “Norman,” Zeus commanded, “Tell me about your life.”

“It’s a long story, Son of Cronus,” I said.

“Not a problem,” responded Zeus, “We have all eternity.”

“Okay. Well, I was born in 1942 in Brooklyn. I married and had three children. I studied chemical engineering and graduated in 1964 from. . .”

“Norman,” King Zeus interrupted, “I know all that. What I’m interested in is the C-301A, the new coker fractionator you designed for the Saturn refinery in Los Angeles.”

“Well, this was a 26-ft-I.D. by 112-ft tangent-to-tangent tower that. . . .”

“Tangent to tangent was 112 ft and 4 in.,” Hera corrected.

“Yes, Immortal Queen Hera, it was 112 ft and 4 in. C-301A was a new tower. The largest coker fractionator on Earth.”

“And how about C-301, the existing 17-ft-I.D. tower?” asked Pallas Athena.

My exit interview had taken an unpleasant turn. In 45 years, I had designed hundreds of distillation towers. Why did Zeus have to select this tower—the project that I would least like to dwell upon? Especially the fate of the old C-301 coker fractionator.

“Rulers of Heaven, it was all so long ago. Anyway, it wasn’t my fault. I had a contract for \$132,000. Don, the project manager, told me what Saturn wanted. It was Don’s fault. Not mine. The scope of work was defined by my client. I’ve forgotten the details. How about my revamp of the El Dorado polypropylene plant? Would you like to hear about. . . .”

“Norman,” Zeus thundered, “Thou hast sinned. Man was made in God’s image, the steward of the Earth. Have you been a good steward of this small planet, unique unto all the heavens?”

SATURN’S COKER FRACTIONATOR

In 1966, I had revamped the Amoco viscous polypropylene unit at El Dorado to increase its capacity by 60%. Amoco was going to build a new plant to get the extra 60%. But I realized that I could “de-bottleneck” the unit by 60% by converting a natural-circulation refrigerant evaporator into a forced-circulation refrigerant evaporator (see Chapter 12). All I needed was a new refrigerant pump and some 6-in. piping. But Zeus wasn’t interested in that project.

Actually, I remembered the coker project in Los Angeles in detail. However, my plan to blame Don, the project manager for this fiasco, was a nonstarter in the eyes of the Immortals. So here’s what happened. Maybe you can say a prayer for me.

OBJECTIVES OF DELAYED COKER EXPANSION

Figure 1-1 is a simplified sketch of a refinery delayed coker. The coker had a capacity of 60,000 bsd, as limited by the flooding in the fractionator. The objective of the expansion project was to increase the capacity to 75,000 bsd. I had been retained to prepare a process design to achieve this 25% expansion. My plan was to reuse the existing C-301 fractionator by:

- Increasing the fractionator operating pressure by 8 psig.
- Reducing the recycle of coker gas oil to the coke drum by leakproofing the gas oil pan chimney tray.
- Minimizing the use of unneeded purge steam used at various points associated with the coke drums.

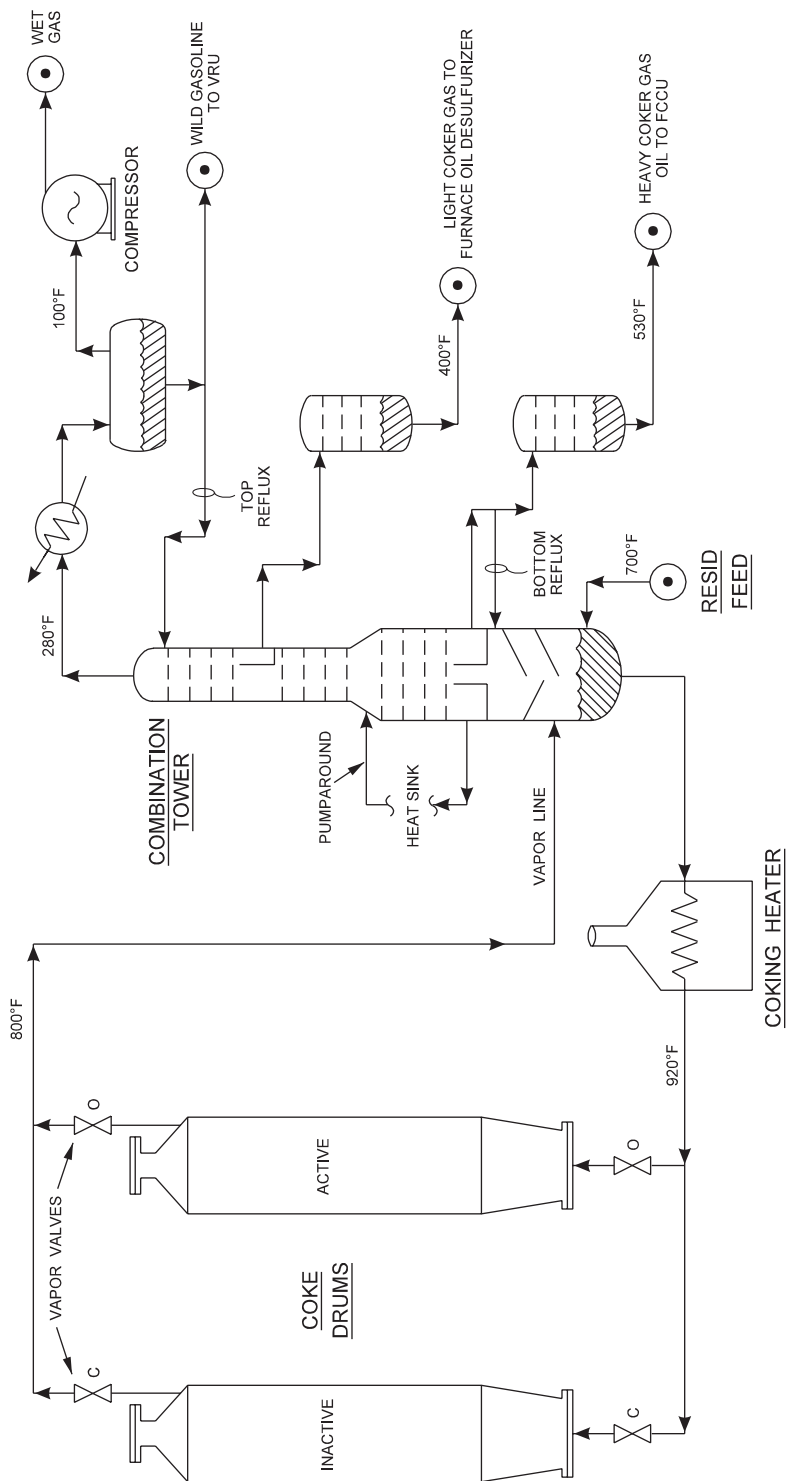


Figure 1-1 Simplified process flow diagram of a delayed coker.

- Increasing heat extraction on the gas oil pump-around loop.
- Drilling holes near the tray rings and tray panel seams in the tray panels that did not have any room for valve caps, to optimize the hole area at 13 to 15% of the tray active area.
- Sloping the tray downcomers, to increase the tray deck area.
- Reducing the outlet weir heights to a minimum on the critically loaded trays.

CHANGING TRAY PANELS

As an alternative to modifying the existing tray panels, one could change the tray panels without modifying the existing tray rings supports and still reuse existing downcomers. When done properly, an increase of 5 to 15% in the tray vapor-handling capacity will result. Changes that are required include:

- Cutting off the bottom edge of the downcomers (about the bottom 4 in.) and restricting the downcomer bottom to preserve the downcomer seal.
- Adding a push-type valve tray panel below the downcomers.
- Replacing the tray panels with Provalves (from Koch-Glitsch) or MVG Grid Trays (from Sulzer-Nutter).

Part of the extra capacity results from using the area under the downcomer for vapor flow. Part comes from pushing the liquid across the tray deck, which equalizes the liquid level on the tray deck and thus promotes more even vapor flow to each tray.

REDUCING THE GAS OIL CONTENT OF FEED

My other proposals would decrease Saturn's excess coker feed by reducing the gas oil content of the delayed coker's feed. The coker feed pumps used a gas oil for seal flush material. These were older pumps, with archaic mechanical seals. Four pumps were involved. Each had both an in-board and out-board mechanical seal, for a total of eight seal flush points. Each seal flush point consumed about 3 gpm of gas oil:

$$(8)(3 \text{ gpm})(1440 \text{ min/day}) \div 42 = 840 \text{ bsd}$$

(Note: An idle pump uses 60% of the seal flash used by a running pump.)

Thus, 1% of coker feed was recycled gas oil. I could change the older seals to modern seals that use high-pressure nitrogen as a barrier fluid. Changing the seals would be inexpensive compared to the cost needed to replace the existing pumps.

(Note: The Eagle-Burgman seal is a good choice.)

I had also noted that the vacuum tower stripping section was not using enough stripping steam. By increasing the flow of the vacuum tower bottoms stripping steam,

I could reduce the gas oil content of the delayed coker feed from 12% to 10%. This would reduce the coker feed rate by about 1200 bsd.

Finally, the flowmeters on the coker heater pass orifice meter connections were purged with gas oil. There were eight passes, each with two orifice tap connections. Rather than continuously purging these 16 orifice tap connections, seal pots packed with gas oil could be used. This would reduce the gas oil content of coker feed a further 250 bsd. Overall, these three indirect methods would decrease the required delayed coker capacity by an additional 3 to 4%.

I had thought that combining all these modest changes would increase the coker capacity by 20 to 25%, or about 72,000 to 75,000 bsd. I knew that raising the fractionator pressure, which would also increase the fractionator capacity, would not be an acceptable option if it also raised the coke drum pressure. The problem was that each increase of 8 psi in coke drum pressure would also reduce the delayed coker liquid yields by about 1.5 liquid volume percent. However, I had also observed that the current differential pressure between the coke drums and the fractionator was about 12 psi. Most of this ΔP (see Figure 1-1) was due to not having full ports in the coke drum overhead vapor valves. The valve port sizes were only 70% of the line sizes. This means that the flow area through the orifice was only half of the flow area through the process lines. As ΔP varies with

ΔP proportional to velocity squared

I could eliminate the majority of the pressure loss through the coke drum vapor lines by replacing the existing vapor valves with full ported valves. Thus, the coke drum pressure would barely change, even though the fractionator pressure would increase from 20 psig (35 psia) to 28 psig (43 psia).

Tower capacity varies inversely with the square root of the absolute pressure. Thus, my single idea of increasing the fractionator pressure by 8 psi would increase the tower's capacity by 11%:

$$\sqrt{43 \div 35} = 1.11 \quad (\text{i.e., } 111\%)$$

"JUST DESSERTS"?

Don, the Saturn project manager, obtained a cost estimate of \$8 million for my design. But my design was rejected by Saturn for several reasons:

- I could not provide an absolute guarantee that the existing coker fractionator would not flood at 75,000 bsd of feed.
- The Saturn project planning department had budgeted \$100 million for this project and capital investment allocations could not be transferred to next year.
- The Saturn plant manager, Larry Overbourne, wanted a new tower.