PROCESS OPERATIONS

LESSONS LEARNED IN A NONTECHNICAL LANGUAGE

PB

PENNWELL BOOKS

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Letter from the Author

I went to university from 1961 to 1964, and I learned nothing. It wasn't that I didn't try. Yet, I have been really successful as a process engineer in designing, operating, and—most importantly—troubleshooting refinery process problems for the past 58 years.

Most of the knowledge that I rely upon consists of things I've learned from troubleshooting home repairs, swimming pool maintenance, and air-conditioner problems. I am a real expert of any and all toilet hydraulic failures.

Also, I had a wonderful high school science education, which I apply all the time—like, PV = NRT and 34 feet of water = 1 Bar.

This book wouldn't be possible without the support of the *Oil & Gas Journal*. Throughout my career I have contributed many articles and the foundation of this book comes from the "Beyond back-to-basics: Process principles and concepts" article series.

I hope my book helps you in your job in the process industry.

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Introduction

I began my refinery troubleshooting career as a child, by wondering and worrying about the ordinary things that other, more normal children take for granted—things such as the steam radiator heater in the bedroom I shared with my older sister, how a drop of water dances around on the surface of a smooth frying pan, and why the water level in our toilet bowl would rise and lower a bit on very windy days. As a young boy, I had very little purpose in observing these oddities of the world around us. I suppose, in retrospect, that my interest in water, fire, wind, and air, was an outgrowth of a lack of cell phones, email, television, and microwaves—things that did not exist in 1948, when I was 6 years old. But perhaps the lack of exposure to the "Age of Computers" permitted me to develop the skills that I will be explaining to the readers of this book in the following chapters.

The purpose of this book is to tell process technology stories relating to things that have happened to me. I'm mainly interested in processes such as:

- Combustion
- Evaporation
- Flow of fluids
- Corrosion
- Solubility
- Boiling
- Vaporization
- Condensation
- Heating
- Pressure
- Refrigeration
- Cooling

My real passion in life is *steam*. Many of my stories concern this theme:

- Steam reboilers
- Steam turbines
- Steam vacuum ejectors
- Reciprocating steam engines
- Stripping steam

Process operation and engineering are complex branches of human knowledge. The process operator or engineer designs, operates, and troubleshoots the following:

- Petrochemical plants
- Refineries
- Pharmaceutical plants
- Food processing facilities

- Distilleries
- Steam and power plants
- Waste water treatment
- Water purification plants
- Hazardous waste disposal units

Their work has a lot to do with these topics:

- Combustion
- Chemistry
- Plumbing
- Thermodynamics
- Corrosion
- Hydraulics: Fluid flow
- Vapor-liquid equilibrium
- Heat balance
- Process control

I've related my observations drawn from everyday life into stories that I have applied to process problems. The key to safety and profitability in process units is to understand how things function. My success as a process engineer is a consequence of the ability to solve process plant problems using simple methods and grade school calculations. This is not a result of my engineering degree. It's based on observations I have made in all kinds of circumstances:

- As a child in our kitchen in New York
- Caring for my swimming pool in Louisiana
- Repairing toilets in my house in Illinois
- Studying a steam radiator in my bedroom in Washington
- Trips on a river steamboat on the Mississippi River
- Considering how my fireplace draws in combustion air in Texas
- Watching swirling water in a river in California
- Flying a kite
- Operating a microwave
- Watching water boil in an old frying pan

Geared to young and seasoned professionals alike, *Process Operations: Lessons Learned in a Nontechnical Language* is designed to present a straightforward approach to mastering the principles and concepts all process engineers should be able to apply without the need of a computer. While simulations and models are useful for examining long-term operational issues, they cannot replace the dimension of human logic and reason required when tackling the array of complex—and sometimes life-threatening—situations that occur in process plants. Using experiences from my more than 58-year career in the process industry, *Process*

Operations: Lessons Learned in a Nontechnical Language provides approaches to understanding core process concepts in ways that will equip the engineer to walk out of an office into a plant and directly resolve process deficiencies via small operational changes or simple retrofits.

The book is setup to be an on hand reference for you. It is not necessary to read it in sequential order. You will find the format of each chapter to be the same. Each chapter begins with an introduction of the subject followed by a purpose. Once each topic is explained the chapter closes with a Lessons Learned section.

1

Applying Technology at Home

Nucleate Boiling

I had just bought a new mug at Walmart; it was smooth and shiny, with no scratches. I filled the mug with water and put it in the microwave for 5 minutes. Nothing happened—the water did not boil. Puzzled, I set the very hot mug on the counter. Nothing happened.

I dropped a tea bag into the "super-saturated" water. The water exploded out of the mug with tremendous violence. The rough surface of my tea bag had provided sites for nucleate boiling to be initiated.

My mom had two frying pans. One was a very old, scratched pan that she inherited from her grandmother. She also had a new, smooth, stainless-steel pan—a present from my dad. If I heated the old pan on the stove for 10 minutes and gently dropped a tablespoon of water on the hot surface, the water would flash to steam and be entirely evaporated in a second.

If I heated the new, smooth pan on the stove for the same 10 minutes and, again, carefully deposited a tablespoon of water on its hot surface, the water would dance around on the pan without boiling. It would slowly evaporate over a period of several minutes.

Strange to say, the hotter the new stainless pan got, the longer it required for the tablespoon of water to evaporate. But, for the old cast iron pan, the hotter it was, the quicker the water would evaporate.

High School Chemistry Lab

The main purpose of attending high school is to meet girls. A secondary objective is to learn to use "boiling stones" in the chemistry lab. If you forget, when you attempt to agitate a flask's contents with a stirring rod, the contents may explode in your face.

This often is not a problem. If the lab flask is old and scratched, nucleate boiling sites probably already exist. Boiling stones, which provide these points where vaporization can be initiated, are not needed.

Low-reflux Rate—El Dorado, Arkansas

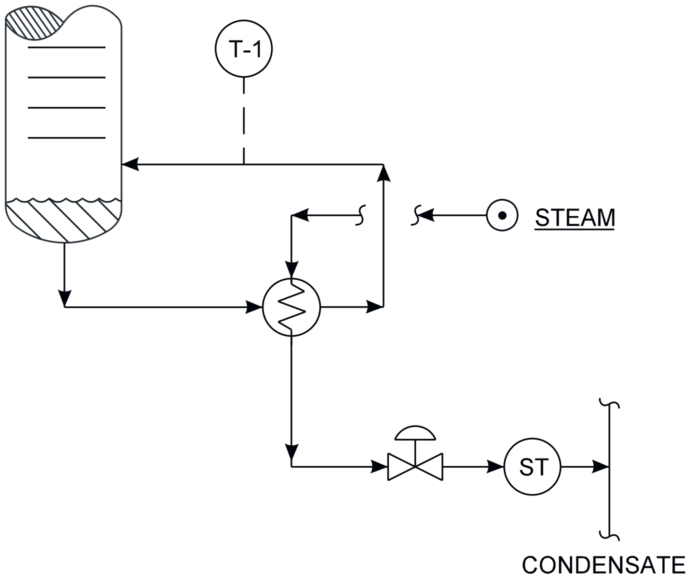

Fig. 2–7. Steam traps can either blow-thru or back-up. Either will reduce reboiler duty.

- Limit—Fractionation was poor because of low-reflux rates. When the reflux rate was raised, the reflux drum level declined, and the reflux pump lost suction.
- Background—The problem of the low-reflux rate was lack of reboiler duty. That is, the reflux comes from the reboiler vapor. Reboiler duty is low because either (a) team condensate is backing up, or (b) steam is blowing through the exchanger. That is, "loss on the condensate seal," due to a steam trap malfunction.
- Solution—To discriminate between these common problems, I slowly began to close on the steam condensate outlet flow. Simultaneously, using my infrared temperature gun, I monitored the reboiler process outlet temperature (T-1) (Fig. 2–7). If the problem was condensate backup, this would lower the process outlet temperature.

  If the problem was steam blowing through (i.e., loss of the condensate seal), this would increase the process outlet temperature at T-1.

  In this instance, the problem was improper maintenance of the condensate seal, due to a faulty steam trap, which was blowing through.
- Follow-up—Best to have a condensate drum and then pump the condensate to the collection system. Steam traps can either blow through, or fail closed, and cause condensate backup.

I'm currently working for Carl, the technical manager of an 80,000-BSD refinery in the Midwest. Carl's problem is bad fractionation in a naphtha fractionator. The tower makes two products:

- Light naphtha—Feed to a pentane-hexane isomerization unit, that changes straight-chain molecules to branched chains. Too many heptanes will coke-up the catalyst.
- Heavy naphtha—Feed to a naphtha reformer. Benzene precursors will increase benzene in gasoline product to an unacceptable level.

Fractionation will now either get better or worse as I apply the above procedure. If it gets better, it means that fractionation efficiency was being degraded due to tray deck weeping. If the separation efficiency degrades at higher rates, the problem was entrainment or flooding. If it improves, then the problem was tray deck weeping.

Back-to-Back Trays

The edge of each tray panel is bent down by 90 inches. Then the vertical edges are thru-bolted together. This creates, in effect, a half of an I-beam support at the edge of each tray panel. This type of assembly greatly increases the rigidity of the tray panels, and reduces the tendency of the tray to sag and hence develop low tray efficiency, especially at reduced vapor flow rates.

Equilibrium Separation Stage

I was the first person in history to design a complex fractionator that was actually constructed using a digital computer program. By complex fractionator, I mean a distillation tower that had multiple side-stream product strippers and draws, multiple pumparounds to remove heat, and several feeds (both vapor and liquid).

The tower was the "B" delayed coker at the American Oil Refinery in Texas City. Designed in 1966 and commissioned in 1968, it's still in operation at the Marathon Refinery (as of 2021). I visited it just last year. You can see it from Farm-to-Market Road 1764.

I had to create my own computer program in those early days of digital technology. Each theoretical stage (or tray) I represented by one *equilibrium separation stage*. This consisted of mixing liquid from the stage above with vapor leaving the stage below, at 100% mixing efficiency—then, separating the resulting mixture of phases, with 100% separation efficiency. Both the enthalpy of the vapor and liquid, and the molal components of vapor and liquid, I assumed were perfectly mixed.

"Okay! I'll be right over. Don't forget the pass steam. We don't want to coke up the tubes."

Upper Explosive Limit

I stood on the Mississippi River levee, 200 feet back from the heater. Black smoke blew out of every sight port, and oily flames raced from the stack. Tom was blocking in the fuel gas and lining up the pass steam to the coils to blow out the residue before it coked up.

Barry was closing the 4-inch heater feed valves on all four passes and making sure the control valve bypasses were shut.

It looked bad. But, in reality, the heater was in a safe position, because the heater firebox was in a fuel-rich situation above its upper explosive limit. It was too fuel-rich to explode.

I knew this because I could see unburnt hydrocarbon vapors from the failed tube igniting in the flue gas that was racing out of the heater's stack. Of course, the concentration of hydrocarbons in the firebox would diminish with time as Barry blocked in the feed and closed off the fuel. And then, as the fuel-to-air ratio diminished, the heater box would drop into the explosive region. And then—the box would explode. I had seen this happen before.

Snuffing Steam

Barry should have introduced snuffing steam into the firebox at this time. This would have retarded the airflow into the firebox, and allowed the box to cool off in an air-deficient environment. That is, the steam would have raised the box pressure above atmospheric pressure and temporarily precluded airflow into the box due to draft.

But I knew Barry would not do this. A few months back, I had the snuffing steam lines blinded off from the visbreaker heater.

But why?

Because the snuffing steam lines were full of steam condensate. Their use would have blown water into a 1600°F brick box and created a pressure surge, which would have blown burning visbreaker tar all over the plant (Fig. 11–1).

I had suggested to Barry that, in the event of a tube failure, he instruct the operators to close off the air registers underneath the heater and shut the stack damper. This would prevent an explosive mixture of air and fuel from developing inside the firebox.

"Okay, Lieberman. In the event of a busted tube, I'll call you to close off the damper and air registers. I'm not gonna ask any of my guys to risk their lives."

Increasing Available Starting NPSH in Casper, Wyoming Refinery

"Joe, first we'll increase the drum set point pressure by 10 psi.

"Next, we'll open the discharge valve (see Fig. 13–2) by one quarter of a turn.

"Then start the pump, and open the discharge valve, in just a few minutes, all the way," I said.

"No, Norm. That can't help. The suction pressure will increase by 10 psi. But the vapor pressure of the flashed crude will increase by the same 10 psi. According to your equation (1), the increased vapor pressure of the flashed crude will offset the higher suction pressure."

"Joe, after 10 minutes, what you say is true. But, at first, due to the 10-minute residence time of liquid in the drum, the higher vapor pressure liquid, formed at the vapor-liquid interface, will not migrate into the pump suction for that 10 minutes. If you can get the pump up and running quickly, you will have a temporary surge of available NPSH.

"Joe, it's a startup trick that I've used. Best to design the equipment elevation properly and allow for the starting, as well as the running, NPSH requirements. Often, while operators are learning this trick, they repeatedly cavitate the pump and damage the $75,000 seal."

Practical Steps to Minimize Cavitation

"Joe, these are steps to protect mechanical seals from damage due to cavitation:

1. Place a pressure gauge with a red mark on the pump suction. Train the operators to open the pump discharge valve as fast as possible, consistent with the pressure not falling below this red mark.
2. Raise the suction drum pressure rapidly by a few psi, just before starting a pump. Then reduce the pressure very slowly once the pump is operating.
3. During normal operations, increase flows really slowly. Most experienced operators tend to do this by themselves.
4. Run near the maximum safe drum level.
5. Spray cold water on the pump case and suction line to subcool the liquid.
6. Running two pumps in parallel requires a lot less NPSH—but is often difficult to control.
7. Injecting a subcooled liquid slip-stream into the pump suction will increase available NPSH.
8. A discharge spill-back to the suction line diminishes the available NPSH and also increases the required NPSH.