## 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.”

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*Process Engineering for a Small Planet: How to Reuse, Re-Purpose, and Retrofit Existing Process Equipment,* By Norman P. Lieberman

“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.

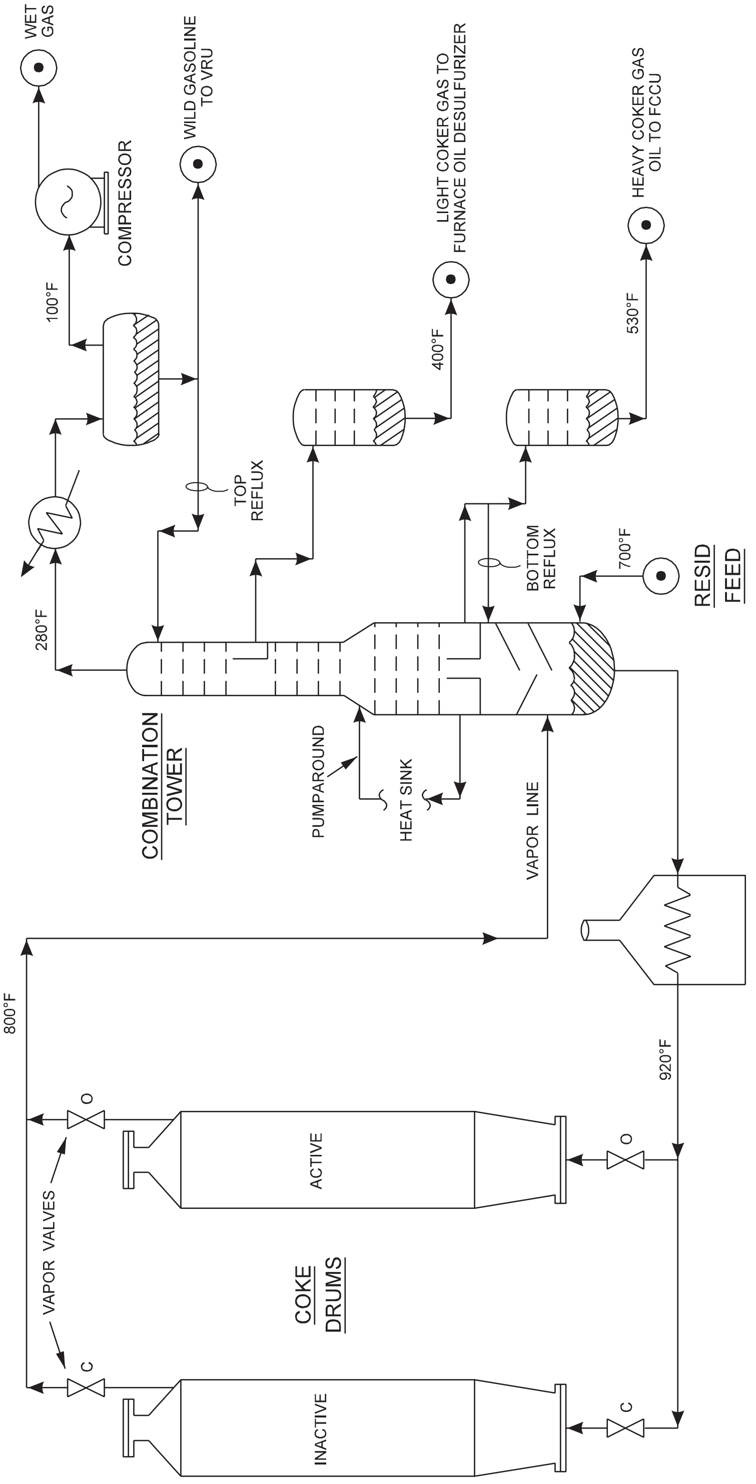

***Figure 1-1*** *Simplified process flow diagram of a delayed coker.*

- 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 $\Delta P$ (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 $\Delta P$ varies with

$$\Delta P \text{ proportional to velocity squared}$$

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.

“It’s okay, Norm,” Don explained. “We realize that a new contract is required. I’ve already generated a new purchase order for your additional work. Just design the new coker fractionator so that it won’t flood at 80,000 bsd and 20 psig operating pressure. The bigger the better. That’s the way Mr. Overbourne thinks.”

“But, Don,” I responded, “I’ve spent so much time on the revamp of C-301. I think it will do the job. The capacity of the unit will be limited by the size of the coke drums to less than 75,000 bsd anyway. Mr. Overbourne’s 80,000 bsd feed rate target is completely unrealistic. The coke drums will limit unit capacity to. . . .”

“Norm, the new purchase order for your work is $132,000—a lump sum,” Don said. I couldn’t think what to say. That’s a lot of money and I knew I could do the entire design in just two weeks. So I changed the subject.

“Look, Don, the wet gas compressor will not be big enough. Not with the fractionator running at only 20 psig and 80,000 bsd of feed. That’s my main reason for raising the coker fractionator pressure by 8 psig. The resulting higher wet gas compressor suction pressure, from 10 psig to 16 psig, will allow me to raise the unit charge from 60,000 bsd to maybe close to 75,000 bsd. Also, I could. . . .”

“No, Norm. You’re not listening,” Don interjected. “Mr. Overbourne also wants a new 12,000-hp compressor.”

“But, Don, there’s nothing wrong with the existing 9000-hp compressor. Anyway, the electrical substation won’t handle the extra load.”

“Lieberman,” Don concluded in a firm voice, “I’ve a meeting to go to. So let’s wrap this up. Listen to me:

- *First point.* The $100 million includes the cost of all electrical work, especially a new substation.
- *Second point.* If you don’t want the work, Wild Horse Engineering will be happy to take over.
- *Third point.* You should show more respect for Saturn management.”

So I signed the contract. And now I had to answer for the new C-301A fractionator. But it wasn’t my fault. Maybe Moses dropped the tablet with the Eleventh Commandment: “Thou shall not waste the resources of the Earth.” But that’s not my fault either. It’s all Don’s fault. He led me into temptation.

## WET GAS COMPRESSOR

I guess it’s true. The Immortals know the evil that dwells in our hearts.

“Norman,” said the Son of Cronus, “did you know that 16,000 tons of iron ore had to be torn from your small planet to fabricate the new fractionator? Plus 16,000 tons of No. 9 coal. All for what purpose?”

“Well, Master of Mt. Olympus. All for no purpose. As you see, I would trade all of the $132,000 just to get my kayak to the shore. And the L.A. delayed coker was limited to 70,000 bsd of feed by the capacity of the existing coke drums, which with relatively minor process changes, the old C-301 tower could have handled.”

I could see, though, that it was best not to mention again that it wasn't my fault. Not only because Zeus didn't believe me, but because in my heart I knew—and had always known—the truth.

"Zeus, forgive me. I am at fault," I admitted.

"And how about, Norman, the new K-301-A, 12,000-horsepower wet gas compressor?" inquired Athena.

"To answer that question, I'll have to refer to the second law of thermodynamics."

"Yes, the second law of thermodynamics." Hera seemed pleased. "The Titans created the laws of thermodynamics when they separated light from darkness. Yes, they created the laws of science for humankind to use and not to abuse. But you have perverted science in sinful ways."

I had told Don that the capacity of the coke drums was inconsistent with a new and much larger, 12,000-hp centrifugal compressor. It would not really matter, I explained, if the compressor were oversized if we used a variable-speed driver. There were three variable-speed options:

- *Steam turbine.* We could install a 400-psig motive steam turbine, exhausting to a surface condenser operating under vacuum conditions. But Don said that the refinery was short of cooling water and the proposed surface condenser would consume 8000 gpm of cooling water.
- *Gas-fired turbine.* There was plenty of coker fuel gas to burn. But this would require a permit, as a new emission source, from the state of California, which could take years.
- *Variable-speed motor drive.* This would involve the purchase of a relatively expensive motor, as the frequency of electric power to the motor would have to be varied. Unfortunately, Larry Overbourne, the refinery manager, did not like variable-frequency speed control of large motors in critical services.

So we would have to use an ordinary 15,000-hp motor. (The compressor rating was to include a 10% capacity safety factor, and the motor was sized for 110% of the compressor load.) I tried to explain to Don that we could never need a 15,000-hp electric motor. It was way too large for the capacity of the coke drums.

"Norm," Don responded, "our Mississippi refinery has a 15,000-hp compressor and we want one of the same size. After all, they have the same-size coke drums as we do."

As the Saturn refinery in Mississippi is close to my home in New Orleans, Don flew from LAX to Louis Armstrong International Airport. We drove to Mississippi. Figure 1-2 summarizes what we saw. The compressor suction valve was almost closed. The pressures were:

- *Compressor suction:* 2 psig (17 psia)
- *Compressor discharge:* 265 psig (280 psia)
- *Pressure upstream of the suction throttle valve:* 20 psig (35 psia)

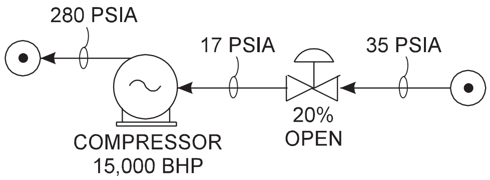

***Figure 1-2*** *Energy loss across a compressor suction throttle valve.*

Compression work per mole is proportional to the compressor suction pressure, as follows:

$$\text{compression work} \sim \left(\frac{p_2}{p_1}\right)^{0.20} - 1$$

where $p_1$ and $p_2$ are, respectively, the compressor suction and discharge pressure in psia. The exponent 0.20 is calculated from $k$ (the ratio of the specific heats) as follows:

$$k \text{ for coker wet gas} = 1.25$$

$$\frac{k-1}{k} = \frac{1.25 - 1.00}{1.25} = 0.20$$

Assume that we have two cases:

- *Case I:* suction pressure = 17 psia, suction valve 20% open
- *Case II:* suction pressure = 35 psia, suction valve 100% open

Case I requires roughly 40% more horsepower than case II. This means that approximately 30% of the motor driver horsepower is lost across the compressor suction throttle valve when it is 20% open.

## WASTING ELECTRIC ENERGY

I explained to Don that 2500 kW were being wasted at the Mississippi plant by the suction throttle valve. To generate 1 kW of electric power may require 9000 Btu/hr of fuel. In older power stations, it is likely to be 10,500 Btu/hr. Therefore, the waste in energy was

$$(2500 \text{ kW})\ (9000 \text{ Btu/hr}) = 22{,}500{,}000 \text{ Btu/hr}$$

There are 6,300,000 Btu in a barrel of fuel oil. Therefore, the Mississippi wet gas compressor was wasting about 80 bsd worth of fuel a day. A typical family in the United States consumes 0.20 barrel of crude oil a day. Therefore, the suction throttle valve was wasting the amount of crude oil that 400 families would use each day.

But Don said, "Interesting, but irrelevant. Saturn has already issued the purchase order for the new compressor and motor. I'd better be careful, though, not to oversize the new compressor's suction throttle valve."

"Don, Saturn could pay a 10% cancelation fee for the compressor. The electric power saved could be exported to Los Angeles. Think of all the $CO_2$ emissions we could avoid. The concentration of greenhouse gases has been increasing at 0.5%, compounded annually, since 1975. We've got to draw the line somewhere. Why not here? Why not today?"

"Norm, I told you, Mr. Overbourne wants the new compressor."

## ALTERNATIVES TO THE NEW COMPRESSOR

"Pallas Athena, the new 15,000-hp motor was not my fault. I tried my best. There was just nothing I could do."

"Do you not fear the shades of Hades?" asked Athena.

"Not really. It's probably like the Good Hope refinery, in St. Charles Parish, Louisiana, where I used to work."

"Norman, look unto thy heart. Were there no alternatives to the new, larger centrifugal compressor?" asked the daughter of Zeus.

"Creator of Wisdom, I did have a few ideas along those lines:

- The air-cooled condensers just upstream of the compressor knockout drum were dirty. I could have cleaned their exterior to increase airflow. This would have lowered the reflux drum temperature shown in Figure 1-1. The reduced reflux drum temperature would alter the vapor–liquid equilibrium so as to produce less vapor. Also, compression work is reduced, as the compressor suction temperature is reduced, in proportion to the reduction in absolute temperature (°R or °K).
- The tube side of the air coolers could have been water-washed on-stream. Not only would this have improved cooling, but more important, the tube-side pressure drop could have been reduced. At a constant fractionator pressure, this would have raised the wet gas compressor suction pressure. Each 1 psi reduction in condenser $\Delta p$ would have reduced the suction volume by over 4%. Further, the lower $\Delta p$ value and the resulting higher reflux drum pressure would alter the vapor–liquid equilibrium so as to produce less vapor.
- The compressor could be kept clean by spraying about 1 wt% of heavy coker naphtha into the suction of the machine. Enough naphtha is used, depending on its molecular weight, to keep the compressor effluent slightly below its dew-point temperature—the idea being to keep the rotator wheels wet, which retards dry-out of salt deposits on the final stage wheels.
- Most of the time, cooler ambient conditions in Los Angeles prevent the coker from being limited by the wet gas compressor. During late afternoon summer days, water can be sprayed as a fine mist into the inlet of the forced-draft air

fans. This will cool the air by 10 to 15°F due to the evaporation of the water, rather like the swamp coolers used in the south western United States. I've also seen the Russians use this technique in Lithuania and it works fine. It's a nice trick to use to reduce the flow of wet gas during peak ambient temperature periods.

- Changing from trays to beds of structured packing in the fractionator would reduce the fractionator $\Delta p$. This would raise the compressor suction pressure by an equivalent amount, but without raising the coke drum pressure.
- The interstage compressor water coolers were badly fouled. They could have been cleaned with inhibited, dilute hydrochloric acid to remove the hardness deposits on the water side. This would have reduced the vapor load to the compressor's second stage by increasing the flow of cooling water and thus decreasing the interstage knockout drum temperature. Alternatively, a chelating solution could have been circulated through the cooling water circuit, to clean the entire cooling-water circulating system.
- The air-cooled compressor discharge condenser could also have been cleaned, on both the tube and air sides. This would have reduced the discharge condenser pressure drop and thus reduced the compressor discharge pressure. This is relatively unimportant, as a 10-psi reduction in discharge pressure is equivalent to a 1-psi reduction in suction pressure as it affects the wet gas compressor compression ratio.
- The existing motor had a habit of tripping off on electrical overload. This could have been because the full-limit amperage (FLA) trip point setting was accidentally set too low. Alternatively, and more likely, the insulation integrity of the copper coil windings had deteriorated, and the motor would have to be rewound. This is not uncommon in larger motors that have seen many years of service close to their FLA point.
- Improving the cleanliness of the compressor rotor by the heavy coker naphtha spray at the suction would also help the motor. As the cleaner rotor would require less horsepower to spin, the amperage load on the motor would also be reduced.
- Another option would have been to modify the. . . ."

"Enough!" commanded Zeus.

"Merciful King of the Immortals, I sent the plant manager, Mr. Overbourne, an email with my suggestions for reusing the existing wet gas compressor and motor. But I never received a reply."

"That email! Unfortunately, it was lost in cyberspace," Zeus explained.

"But Master of Thunder, that's not my fault. I think it was returned by a Mailer Demon."

"Your sin is one of omission. You should have asked for an appointment with Overbourne. You should have insisted on your ideas. The construction of the new motor and compressor consumed resources on your little planet that will take eons to replace. Just the wasted electrical power produced more carbon dioxide emissions than Adam and Eve, who lived for 900 years," Queen Hera explained.

"Queen Hera, where's Larry Overbourne now?" I asked.

Zeus's countenance darkened, "Vengeance shall be mine. Seek for him across the River Styx, in the House of Hades."

I just hung up the phone. Don was telling me that my new fractionator and compressor designs are working great. Demonstrated capacity is overdesign and all products are on-spec.

Unfortunately, the refinery is cutting the crude run because gasoline demand is slipping due to the economic turndown. Also, the coke drums themselves are cracking due to the shortened coke drum cycles. So the extra capacity isn't needed. But still, Saturn's management is pleased with the project. I just didn't have the heart to tell Don what the ultimate top management thought about our work.

## KEEPING COMPRESSOR ROTORS CLEAN

Of the preceding list of items to improve a compressor's efficiency and capacity, the one from which I have seen the most beneficial results is the injection of a liquid spray into the suction of the compressor. This is such a beneficial practice when compressing most process and natural gas streams that I have often wondered why it is not a standard feature in most centrifugal compressor's original installations.

When I was first asked, as a young process design engineer at the old American Oil Company in 1965, to design a liquid injection system for the suction of a multistage recycle hydrogen centrifugal compressor, I was quite confused by the assignment. All compressors that I had seen were equipped with compressor K.O. (knockout) drums, to prevent liquid from damaging the compressor internals. Both entrained droplets and slugs of liquid will damage the valve plates on a reciprocating compressor. A broken valve plate will, in practice, disable the affected reciprocating compressor cylinder and lead to a loss of compression efficiency and capacity. Slugs of liquid (but not necessarily entrained droplets of liquid) will also damage both the rotor and stator of a centrifugal compressor. Hence the need for the K.O. drum ahead of the compressor's suction.

Let's assume that there is a small amount of entrained liquid in the suction of a centrifugal compressor. Actually, according to Stokes' law, that's not an assumption but a certainty. Let's further assume that this entrained liquid contains a tiny amount of salts. Again, that's not an assumption, but a certainty, if we are compressing:

- Coker off-gas
- FCU (fluid cracking unit) wet gas
- Refinery hydrotreater recycle gas
- Naphtha reformer off-gas
- Natural gas upstream of the glycol dehydration scrubber

As the gas is compressed, one might think that the higher pressure would prevent any droplets of entrained liquid from evaporating. However, the heat of compression is always a bigger factor promoting compressed gas to dry out, and it offsets the effect of the higher pressure entirely. Thus, as the inevitable droplets of liquid in the inlet gas evaporate, salts and other solids may slowly accumulate on the compressor wheels.

My most vivid experience of this common problem occurred at the Laredo compression station in south Texas in 1986. We were compressing natural gas from 600 psig to 1100 psig using a centrifugal compressor comprised of four wheels. The gas contained entrained brine (i.e., salt water). After several months of operation, I would begin to notice a gradual loss of compressor capacity. Not only would the compressor's capacity and efficiency diminish with time, but when the compressor lost about 30% of its capacity, the compressor would start to vibrate and then trip off on the high rotor vibration automatic shutdown switch. When, subsequently, the machine was disassembled, I observed that:

- The first wheel was very clean.
- The second wheel had minor salt deposits.
- The third wheel was badly encrusted with both salt and a heavy grease.
- The final and fourth wheel was very slightly fouled with salt.

Clearly, the brine was drying out on the third wheel. The resulting deposits were restricting the gas flow through the machine: thus the loss of capacity.

## CALCULATING LIQUID INJECTION RATES

A typical application in a refinery for suppressing salt formation on a centrifugal compressor's rotor, would be hydrogen recycle for a naphtha hydrosulfurizer. To calculate the amount of the liquid injection to the suction of the compressor:

- Assume that the entrainment rate is zero from the K.O. drum.
- Select the type of liquid to be employed. I would just use the naphtha stabilizer bottoms rather than an expensive specialty aromatic chemical.
- Calculate the amount of naphtha that is required in the compressor's suction to reach the dew-point temperature at the discharge from the final wheel of the stage.
- Note that each stage of compression (i.e., not each wheel) should be treated separately.
- To calculate the amount of naphtha required, take into account both the latent heat of evaporation of the naphtha and the increase in the dew-point temperature of the compressed gas, due to the gas's increased molecular weight, from the injected naphtha.
- A typical spray wash flow is 1 wt% of the gas flow. I do not add any safety factors to the amount calculated above, as ignoring the effect of entrainment in the feed gas in effect adds a safety factor to this calculation.

## DESIGN DETAILS

Then I call my Bete nozzle rep and have him select an appropriate mist nozzle for this application, I will typically specify:

- $\Delta p = 20$ psi
- Nozzle to be extractable on-stream, through a packing gland
- 316 (L) stainless steel
- External filter, with mesh openings of one-third the maximum free passage of the mist nozzle

Running without the spray while it is being cleaned for a few hours is okay. However, forgetting to shut off the naphtha spray when the compressor trips off is definitely not okay. Thus, the FRC regulating the spray wash flow should be tripped when the compressor is shut down.

I realize that changing the fractionator tray panels and adding a mist injection system to a wet gas compressor is not entirely consistent with the objective of using what we have. But these methods are a far better alternative to erecting a giant new coker fractionator tower or installing a new oversized wet gas centrifugal compressor equipped with a huge new motor, requiring a new electrical substation. This is what ethical engineering design is all about!

## TROUBLESHOOTING METHOD

In this book I detail a large number of successful examples as to how process problems were resolved, with a minimum input of new equipment. These examples are all genuine and true to life, sometimes taken out of the actual context, but without altering the technical content of the incident. However, what is not true is that I solved all these problems myself. On occasion, the solution was later found by an engineer or operator with whom I had been working.

My failure to solve some problems is usually due to spending only a day or two on a subtle or complex issue. Or, too frequently, I have made a wrong initial assumption and could not resolve the issue until this flawed assumption was discarded.

Still, almost invariably, the man or woman who has defined the correct solution after my departure has credited my troubleshooting method as contributing to their success. This method is as follows:

- Look over the equipment in the field until you become familiar with the function, location, and nomenclature.
- Discuss the problem with the hourly operators in detail.
- Carefully measure all parameters that may interact with the problem. Defining which such parameters to measure is often the most difficult and important key to solving the problem.
- Calculate the effect of process changes on the parameters.
- Observe the effect of the process changes on the parameters. That is, change things and see what happens.
- Does the observed change equal the calculated change? If not, why the difference?

The difference between the observed and predicted parameters is most often the key observation that will reveal the true nature of the problem. So often, in retrospect, the nature of the problem is disturbingly simple. Often, I've become angry at myself for stumbling over an obvious issue. But with age I've come to understand that it's my technique, not knowledge or experience, that is my fundamental contribution to the hydrocarbon process industry.