1
What is Trouble Shooting?

Process plants operate about 28 days of the month to cover costs. The remaining days in the month they operate to make a profit. If the process is down for five days, then the company cannot cover costs and no profit has been made. Engineers must quickly and successfully solve any troublesome problems that occur. Sometimes the problems occur during startup; sometimes, just after a maintenance turn-around; and sometimes unexpectedly during usual operation.

A trouble-shooting (TS) problem is one where something occurs that is unexpected to such an extent that it is perceived that some corrective action may be needed. The trouble occurs somewhere in a system that consists of various pieces of interacting equipment run by people. The TS "corrective" action required may be:

- to initiate emergency shut-down procedures,
- to forget the situation; it will eventually correct itself,
- to return the situation to "safe-park" and identify and correct the cause and try to prevent a reoccurrence,
- to identify and correct the cause while the process continues to operate under current conditions.

Here are two example TS problems.

Example **Case #1**:

"During the startup of the ammonia synthesis reactors, the inlet and outlet valves to the startup heater were opened. The pressure in the synthesis loop was equalized. The valves to the high-pressure stage of the synthesis gas compressor were opened and the firing on the start-up heater was increased. However, we experienced difficulty getting the fuel-gas pressure greater than 75 kPa; indeed a rumbling noise is heard if we try to increase the pressure. The process gas temperature is only 65 °C. What do you do?"

Example **Case #2**:

"The pipe on the exit line from our ammonia storage tank burst between the vessel and the valve. An uncontrolled jet of –33 °C ammonia is streaming out onto the ground. What do you do?"

Successful Trouble Shooting for Process Engineers. Don Woods

ISBN: 3-527-31163-7

Trouble shooting is the process used to diagnose the fault safely and efficiently, decide on corrective action and prevent the fault from reoccurring. In this chapter we summarize the characteristics of a trouble-shooting problem, give an overview of the trouble-shooting process and "systems" thinking used to correct the fault and present an overview of this book.

1.1 Characteristics of a Trouble-Shooting Problem

TS problems share four common characteristics; TS problems differ in their seriousness and when they occur. Here are the details for each.

1.1.1 Similarities among TS Problems

TS problems share the following four characteristics: a) exhibit symptoms of deviations from the expected, b) have tight time constraints, c) are constrained by the physical plant layout and d) involve people.

a) Trouble-shooting situations present *symptoms*. The symptoms may suggest faults on the plant or they might be caused by trouble upstream or downstream. The symptoms may be false and misleading because they result from faulty instruments or incorrect sampling. The symptoms might not reflect the *real* problem. For example, in **Example Case #1** the cause is not that the fuel-gas pressure is too low. Instead, the suction pressure of the synthesis gas compressor was lower than normal, the alarms on the cold bypass "low flow" meter had been disarmed and the *real* problem was that there was insufficient process gas flow through the heater.
b) The *time* constraints relate to safety and to economics. Is the symptom indicative of a potential explosion or leak of toxic gas? Should we initiate immediate shutdown and emergency procedures? The release of ammonia, in **Example Case #2**, causes an immediate safety hazard. Time is also an economic constraint. Profit is lost for every minute when off-specification or no product is made.
c) The *process configuration* constrains a trouble shooter. The process is fabricated in a given way. The valves, lines and instruments are in fixed locations. We may want to measure or sample, but no easy way is available. We have to work within the existing process system.
d) Sometimes the cause of the problem is *people*. Someone may not have followed the expected procedure and was unwilling to admit error. Someone may have opened the bypass valve in the belief that "the process operates better that way." As in **Case #1**, the alarm may have been turned off. The orifice plate may have been put in backwards. Someone may have left his lunch in the line during the construction. Instructions may have been misinterpreted.

1.1.2
Differences between TS Problems

Here are four ways that TS problems differ. Some TS problems pose a) safety and health hazards. TS problems can arise b) during startup, c) after a shutdown for maintenance or after a change has been made and d) during usual operations.

1.2
Characteristics of the Process Used to Solve Trouble-Shooting Problems

The TS process or strategy used differs depending on the *type* of TS problem. Yet, the TS process has five common key elements.

1.2.1
How the Type of Problem Guides the TS Process or Strategy

The four different *types* of TS problems (described in Section 1.1.2) call for different TS strategies.

- Handling trouble that poses a hazard

At the design stage engineers should anticipate causes of potentially unsafe and dangerous operation (through such analyses as HAZOP and fault tree) and prevent hazardous conditions from ever occurring. They should include the four elements of control: the usual control, alarms, system interlock shutdown, SIS, and shutdown/relief. However, despite best efforts trouble can occur – such as in Example **Case #2**.

The TS strategy is to recognize unsafe conditions and initiate emergency measures or, where possible, to return the operation to "safe-park" conditions where operation is safe until the trouble is solved.

- Handling trouble during the startup of a new process

When we start up a process or new approach for the first time, we may encounter trouble-shooting problems. However, because these are "first-day" problems they have characteristics that differ from the usual trouble that can occur on an existing process. Hence, a different set of information or experience, and sometimes approach, can be useful. In particular, four events could cause trouble:

1. garbage or stuff left in the lines or equipment,
2. incorrect installation, for example, a pipe hooked up to the wrong vessel,
3. during startup, there are often many people around to get things going correctly – this can interfere with the lines of communication,
4. residual water or air left in process vessels and lines.

Furthermore, although we have theory and often computer simulations to provide ideas about how the plant or process *should* be operating; we have no actual data. Example **Case #1** is a startup problem.

The TS strategy is to focus on the basic underlying principles and create hypotheses about how the process and operations should function.

The financial penalty is usually higher for delays during startup. The penalties include penalties written into the contract for delays, insurance costs and government regulation costs.

- Handling trouble that occurs after a maintenance turnaround or a change.

Changes that can cause faulty operation include

1. equipment is taken apart for maintenance,
2. processing conditions change because, for example, the feedstock is changed,
3. there is a change in operating personnel.

In these examples, we have information about performance *before* and *after* the change.

The TS strategy is to identify the change that seems to have triggered the fault.

- Handling trouble that occurs during usual operation or when conditions change gradually.

Sometimes we encounter trouble when the process is operating "normally" or when we gradually increase the production rate.

The TS strategy is to focus on the basic underlying fundamentals of how the process works, create hypotheses that are consistent with the evidence and use tests to confirm the hypothesis.

1.2.2
Five Key Elements Common to the TS Process

Skill in trouble shooting depends on five key elements: 1) skill in problem solving, 2) knowledge about a range of process equipment, 3) knowledge about the properties, safety and unique characteristics of the specific chemicals and process conditions where the trouble occurs, 4) "system" thinking and 5) people skills. Here are some details about each.

For *general problem solving*, one of the most important skills is in identifying which evidence is significant and how the evidence relates to appropriate hypotheses and conclusions.

Concerning the importance of *knowledge about process equipment*, the differences between skilled and unskilled trouble shooters are more in their repertory of their experiences than in differences in general problem-solving skills. In other words, it is the knowledge about process equipment, common faults, typical symptoms and their frequency that is of vital importance. A trouble-shooter's effectiveness depends primarily on the quality of the knowledge that relates i) symptom to cause; and ii) the relative frequencies of the symptoms and the likelihood of causes.

Specific knowledge about the chemicals and equipment configuration must be known to handle safety and emergencies. For example, if knowledge of the hazards of ammonia is not known, then Example **Case #2** is not treated with the urgency required.

Trouble occurs in a process "*system*" even though it might initially appear as though it is in an isolated piece of equipment. Equipment interacts; people interact with the equipment. Viewing the trouble-shooting problem in the context of a "system" is vital.

Interpersonal skills are needed. The interpersonal skills needed between the trouble shooter and the people with whom he/she must interact include good communication and listening skills, building and maintaining trust and understanding how biases, prejudice, and preferences lead to interpersonal differences in style.

1.3 Self-Test and Reflections

Reflect on your trouble-shooting skills based on the five common key elements described in Section 1.2.2. Rate yourself-on the five or six elements in each category and then set goals to improve. A rating of 0 means that *nothing is known*. The maximum scale is 10. Descriptions are given for ratings of 1, 5 and 10.

(1) Problem-solving skill as applied to trouble shooting

- Monitoring, being organized and focusing on accuracy: rate: _____

  1 = aware that it's important when problem solving. 5 = monitor about once per 5 minutes, use a personal "strategy", tend to let time pressures dominate. 10 = monitor about once per minute, use an evidence-based strategy flexibly and effectively, focus on accuracy, check and double check frequently.

- Data handling, collecting, evaluating and drawing conclusions: rate: _____

  1 = think of a variety of data to be collected. 5 = systematically collect data that seem to test the hypotheses, unclear of accuracy of data, unaware of common faults in reasoning, emphasis on opinions. 10 = systematically decide on data to collect and correctly identifies its usefulness; aware of the errors in measurements; use valid reasoning, focus on facts, aware of own biases in collecting data.

- Synthesis: creating and working with hypotheses as to the cause: rate: _____

  1 = aware that should have a hypothesis. 5 = can identify several working hypotheses that seem technically reasonable. 10 = can generate 5 to 7 technically reasonable hypotheses for any situation; willing to change hypotheses in the light of new data.

– Decision making: rate: _____

1 = use intuitive criteria. 5 = systematic, consider many options, unaware of any biases. 10 = use measurable *must* and *want* criteria explicitly, prioritize decisions and aware of personal biases and try to overcome these.

(2) Experience with process equipment

– Centrifugal pumps: rate: _____

1 = flow capacity and head, location of inlet and exit, principle of operation. 5 = NPSH and problems related to this, impact of reverse leads on the motor, correct location of the pressure gauge on the exit and the implications of shutting the exit valve, pumps operate on the head-capacity curve and the implications. 10 = implications of worn volute tongue and worn wear rings, lubrication, seals and glands.

– Shell and tube heat exchangers: rate: _____

1 = size area. 5 = size on area and Δp, baffle-window orientation, correction to MTD for multipass system, some options for control. 10 = tube vibrations, steam traps, nucleate versus film boiling and conditions, different causes of fouling, maldistribution issues and can use a variety of control options.

– Distillation columns: rate: _____

1 = estimate the number of trays, know impact of feed conditions, reflux ratio and bottoms and overhead composition. 5 = familiar with a variety of internals and can size/select, size downcomers, issues related to sealing downcomers, familiar with some control options, can describe the interaction between condenser and reboiler. 10 = jet versus downcomer flooding, surface tension positive vs negative, pump arounds, vapor recompression, wide variety of control options.

(3) Knowledge about safety and properties of material on the processes with which I work
I can list the conditions and species that pose:

– Flammable risk rate: _____

1 = can identify individual species and conditions for five chemicals that might produce "flammable risk". 5 = can identify individual and combinations of species and conditions for over 30 chemicals and the process faults or failures that might produce "flammable risk". 10 = can identify individual and combinations of species and conditions for over 100 chemicals and the process faults or failures that might produce "flammable risk".

– Health risk rate: _____

1 = can identify individual species and conditions for five chemicals that might produce "health risk". 5 = can identify individual and combinations of

species and conditions for over 30 chemicals and the process faults or failures that might produce "health risk". 10 = can identify individual and combinations of species and conditions for over 100 chemicals and the process faults or failures that might produce "health risk".

– Explosive risk rate: _____

1 = can identify individual species and conditions that might produce "explosive risk" for five chemicals. 5 = for over 30 chemicals and can identify individual and combinations of species and conditions and the process faults or failures that might produce "explosive risk". 10 = for over 100 chemicals and can identify individual and combinations of species and conditions and the process faults or failures that might produce "explosive risk".

– Mechanical risk rate: _____

1 = can identify pressure and moving equipment risk for about five types of equipment. 5 = can identify overpressure, thermal and moving equipment risk for a P&ID with 20 pieces of Main Plant Items, MPI. 10 = can identify overpressure, thermal, corrosive and moving equipment risk for a P&ID with 50 MPI.

– Unique physical and thermal properties: rate: _____

1 = can identify chemicals and conditions that have "unique properties" for one chemical. 5 = for 10 chemicals. 10 = for 30 chemicals.

(4) "Systems" thinking.

– Faulty operation of and carryover from/to upstream/downstream equipment: rate: _____

Can estimate/predict the effects of pulses, cycling, contamination on downstream equipment. Can predict potential sources of pulses, cycling and contamination from upstream equipment. 1 = for one piece of equipment. 5 = for a P&ID with 10 MPI. 10 = for a P&ID with 40 MPI.

– Impact of environmental conditions rate: _____

1 = can estimate the environmental impact for the atmosphere from about 10 main plant items. 5 = for about 20 MPI and atmospheric, aqueous and solid impact. 10 = for about 50 MPI and atmospheric, aqueous and solid impact.

– Pressure profile: rate: _____

1 = can calculate a pressure profile for one pipe from detailed calculations. 5 = can use rules of thumb to estimate the pressure profile for about five piping configurations. 10 = can estimate pressure profiles for a P&ID with interconnecting piping with 50 MPI.

– Process control: rate: _____

0 = Unable to identify and rationalize a process control system. 5 = For a P&ID with 10 MPI, can identify good and bad process control; can identify the presence and absence of four levels of process control (control, alarm, SIS, relief and shutdown). 10 = For a P&ID with 40 pieces of equipment, can identify good and bad process control; can identify on the P&ID the presence of and absence of four levels of process control (control, alarm, SIS, relief and shutdown).

(5) People skills

– Communication skills: rate: _____

1 = write or speak to tell them what you know, use acceptable grammar and follow expected format. 5 = correctly identifies single audience, answers needs and questions; includes some evidence related to conclusions, reasonably well organized with summary, coherent and interesting, defines jargon or unfamiliar words, grammatically correct and follows the expected format and style. Some misunderstanding occurs in some verbal or written instructions. 10 = correctly identify multiple audiences, answer their needs and questions; include evidence to support conclusions, well organized with summary and advanced organizers, coherent and interesting, defines jargon or unfamiliar words, grammatically correct and follows the expected format and style. Verbal and written instructions are carried out correctly.

– Listening skills: rate: _____

1 = listen intuitively. 5 = aware of some elements of listening and usually can demonstrate *attending*. 10 = aware of the characteristics and foibles of listening, skilled at opening conversations, attending, following and reflecting.

– Fundamentals of relationships: rate: _____

1 = handles relationships intuitively. 5 = aware of most of the fundamentals and unacceptable behavior. 10 = claims and respects fundamental rights and avoids using contempt, criticism, withdrawal and defensiveness.

– Developing and building trust: rate: _____

1 = knows a few principles for developing trust; 5 = understands how to develop trust. 10 = can develop mutual trust naturally.

– Building on another's personal preferences: rate: _____

1 = intuitively aware of own preferences and that others are different. 5 = explicitly aware of own preferred style and aware of uniqueness of others but not very effective in exploiting the differences positively. 10 = familiar with my uniqueness and those of my colleagues and use the differences to improve our work instead of promoting conflict.

Total your scores. Identify the areas with the lowest scores and set goals for yourself. For problem solving, see Chapters 2, 5 and 6. For experience with process equipment, see Chapter 3 and Appendix A. For knowledge about safety, see Chapter 3. For "systems thinking", see Chapter 3 and Appendix B. For people skills, see Chapter 7. If you have high scores in all areas, Congratulations. Go directly to Chapter 8 and enjoy!

1.4 Overview of the Book

This book is about improving your approach to trouble shooting. This book has basically five parts. Chapters 2 and 3 provide details about the mental process and practical knowledge of common symptoms and causes for a variety of process equipment. Chapter 4 gives some examples of trouble shooters in action as they work through a variety of problems. This is included to give you a chance to reflect on your approach. Chapters 5, 6 and 7 provide example training opportunities to polish your skill in trouble shooting in the areas of problem solving, critical thinking and testing hypotheses and interpersonal skills, respectively. Chapter 8 gives cases that you, the reader, can use to polish your skill. The final chapter suggests the next level of considerations to polish your skill further.

1.5 Summary

Trouble-shooting situations present *symptoms*, symptoms that may not reflect the real problem. Trouble shooters are constrained by time and the existing equipment layout. Trouble-shooting situations inevitably include people.

Solving a trouble-shooting problem uses the five elements: skill in problem solving, knowledge about equipment and about hazards, skill in *systems* thinking and people skills.

Problems occur that pose a hazard, when the process is started up for the first time, when the process is started up after change or maintenance or during usual operations or when we are trying to increase the capacity of the process. Slightly different TS strategies are used for the different types of TS problem.

1.6 Cases to Consider

Here are five cases. Consider each and write out the approach you would take to start each. For example, you might ask *What is the problem? What questions might I ask? What are the possible causes? What tests might I do? What samples might be taken for analysis?*

Case #3: The Case of the cycling column

The shut-down and annual maintenance on the iC4 column has just been completed. When the operators begin to bring the column back on-stream the level in the bottom of the column cycles madly, that is, the level rises slowly about 0.6 m above the normal operating level and then quickly drops to about 0.6 m below normal. The process then repeats. You have been called in as chief trouble shooter to correct this fault. It costs our company about $500/h when this plant is off-stream. Get this column working satisfactorily. The system is given in Figure 1-1.

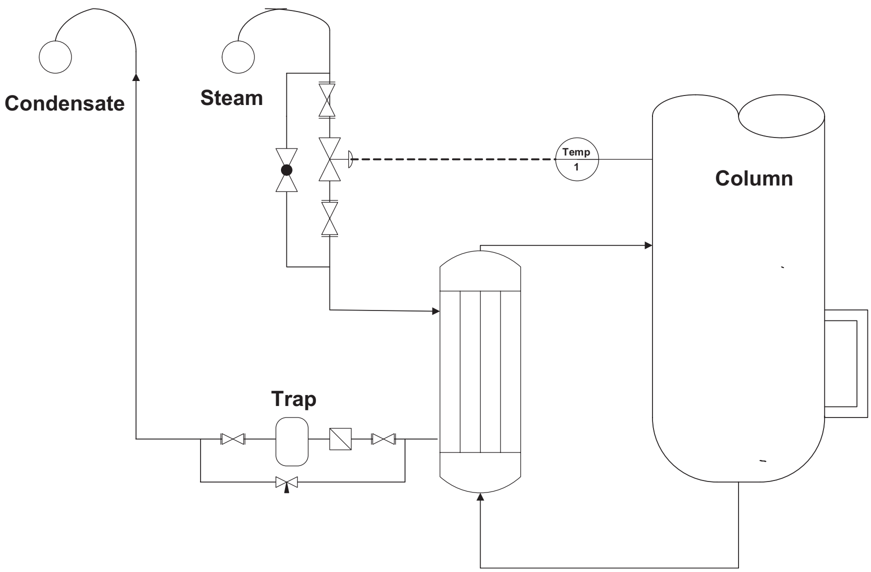

Figure 1-1 A distillation column for Case #3.

Case #4: The case of the platformer fires

Heavy naphtha is converted into high octane gasoline in "Platforming". Byproducts of the reaction include low-pressure gas and hydrogen-rich gas containing 60–80% hydrogen. The products from the platformer reactor (at 4.8 MPa g and 500 °C) are heat exchanged with the feed naphtha to preheat the reactor feed. Figure 1-2 illustrates the layout. In the past three weeks since startup we have had four flash fires along the flanges of the stainless steel, shell and tube heat exchanger. The plant manager claims that because of the differential thermal expansion within the heat exchanger, because of the diameter of the exchanger (1 m), and because it's hydrogen, we're bound to have these flash fires. The board of directors and the factory manager, however, refuse to risk losing the $90 million plant. Although the loss in downtime is $10,000/h, they will not let the plant run under this flash-fire hazard condition. "Fix it!" says the technical manager. Maintenance have already broken six bolts trying to get the flange tighter, but they just can't get the flanges tight enough.

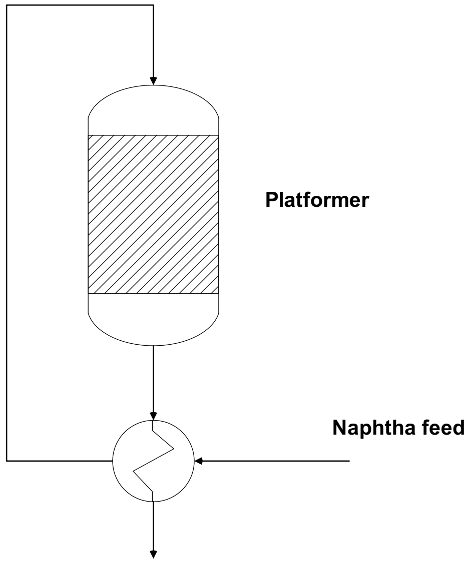

Figure 1-2 The platformer for Case #4.

Case #5: The sulfuric acid pump problem

Dilute sulfuric acid is stored in a horizontal, cylindrical tank in the basement, as is shown in Figure 1-3. The tank diameter is 1.8 m; the length, 3.6 m. An exit line goes from the bottom of the tank and rises 3.6 m up through the ground floor to a centrifugal transfer pump that pumps the acid to a reservoir 7.5 m above the ground level.

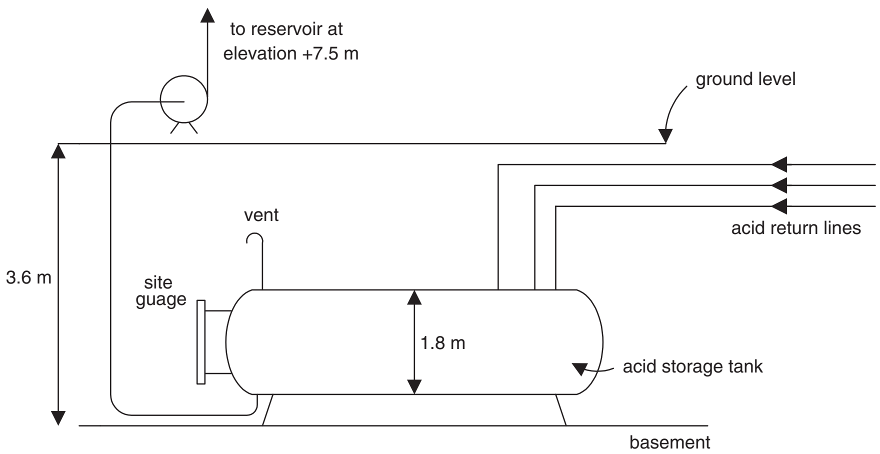

Figure 1-3 The configuration for Case #5.

Acid is recycled to the tank from different parts of the process at such a rate that about every two hours the pump is activated to transfer the acid to the elevated reservoir. However, each time the transfer pump operates, the level gauge at the side of the tank shows that there is still about 0.7 m of acid in the bottom of the tank when the transfer pump makes a "crackling" noise that the operator says "sounds like cavitation". At this time the operator stops the pump. This means that the transfer pump has to operate more frequently than need be and that cavitation may be eroding the impeller. What do you suggest that I do to fix the problem?

Case #6: The case of the utility dryer (courtesy of C.J. King, University of California, Berkeley)

Our plant has a utility air drying unit, which dries all of the utility air used for the pneumatic instrument lines and other purposes. The air is compressed to about 550 kPa g and then passes through the drying unit, the flow diagram of which is attached. For this unit, two beds are hooked in series with the first bed being regenerated and the second bed drying. The first bed experiences two hours of regeneration with hot air followed by a one hour flow of cold incoming air to cool down the regenerated bed. The second bed drys the air for 3 hours. After 3 hours, the flows switch so that the regenerated bed becomes the drying bed and vice versa. The plant operators are following the vendor's instructions in setting the timer dials on the various valves: all the valves (the four way valves, V2 and V3, and the three-way valve, V1) are thrown every three hours. The 3-way valve, V1, is also thrown two hours after a cycle change to send fresh air to cool the regenerated bed. The hot air used to regenerate the bed is heated in a steam heater with the TRC-1 set at 175 °C. The present utility air flowrate through the dryer is 4000 Ndm^3/s or about $^1/_2$ design flowrate. The proportionating valve is governed by pressure P3. At present, full pressure is kept on the valve; the valve is shut so that no air goes directly to the dryer bed. The diagram shows the valve settings for Bed A being regenerated and Bed B, drying. All the air flow goes, via the 3-way valve V1 to the steam heater for the regeneration phase of Bed A. The adsorbent is activated alumina with typically 0.14–0.22 kg water adsorbed/kg dry solid. Each bed contains 5000 kg of activated alumina. The available sample valves are labeled "S".

Now that it is winter we have been experiencing much colder nights, and we have encountered several instances where the instrument air lines have been freezing. This has been traced to the air coming out of the drying unit being too wet, on average. We estimate that this problem will cost us about $8,000 per day until we get it fixed. The job is yours – fix it.

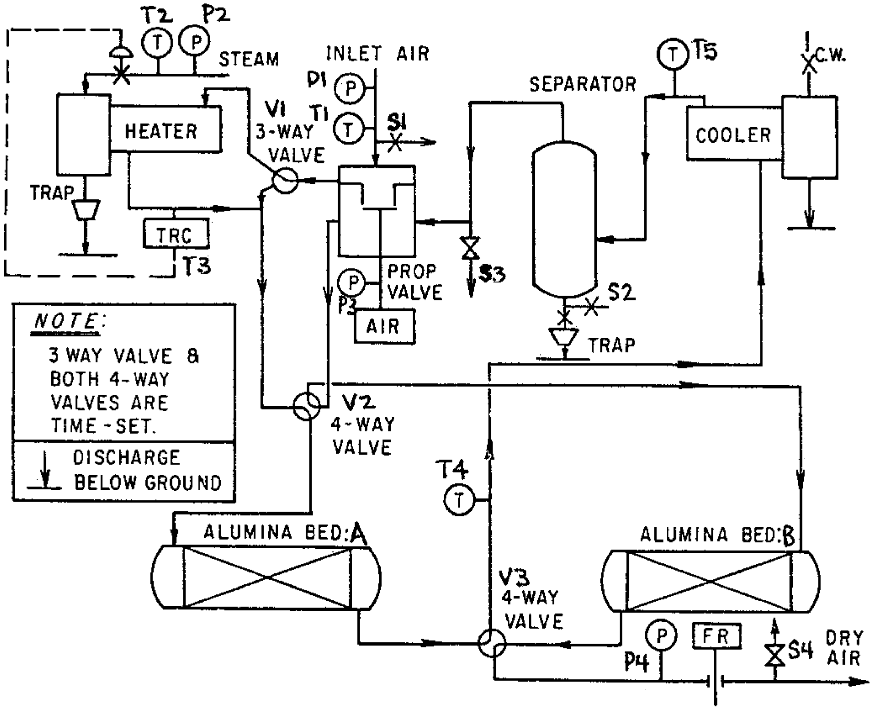

Figure 1-4 The utility dryer for Case #6.

Case #7: The case of the reluctant crystallizer (the case is supplied by W.K. Taylor, B Eng. McMaster, 1966 and used with permission)

Process solution, at 55 °C, enters the vacuum crystallizer (VC) where it is concentrated and cooled to cause precipitation of the product.

Normally, the first and second stage ejectors are used to start syphoning feed solution into the VC until it is two-thirds to three-quarters full. The first hour of operation is done at 6.5 kPa absolute supplied by the first- and second-stage ejectors with city water to the interstage condenser. When the batch cools to 40 °C the booster ejector and the barometric condenser are turned on to give an absolute pressure of 2.5 kPa abs. The batch time is 8 hours during this time the liquid level in the VC slowly drops about 40 to 50 cm. The city water is much colder than the bay water and so to ensure that the temperatures in the barometric leg is less than 26 °C, city water can be used to supplement the bay water. If the booster ejector is turned on too soon, it will not hold but rather *kicks out*. This happens when the steam goes directly into the VC instead of through the ejector nozzle. This phenomena makes a recognizable sound.

Today, the plant operator phones, “The booster does not hold! After about half to one hour of operation it *kicks out*.”

While the booster was holding, the liquid level dropped at such a "fantastic rate" that you could actually watch the level drop, whereas it would normally drop 40 to 50 cm over an 8-hour period.

Pressure gauge **P7** indicated a "wildly fluctuating pressure". The needle jumped back and forth from 140 to 550 kPa g while the booster was "holding".

All the other pressures and temperatures were normal. Here is a summary:

	Pressure, kPa g							
	Steam					Water		
	P1	**P2**	**P3**	**P4**	**P8**	**P5**	**P6**	**P7**
Normal readings	550	550	550	725	550	0–35	310	205
Today	550	550	550	725	550	0–35	310	140–550

	Temperature, °C	
	Barometric legs	
	T1	**T2**
Normal readings	< 27	< 27
Today	< 27	< 27

Figure 1-5 illustrates the system.

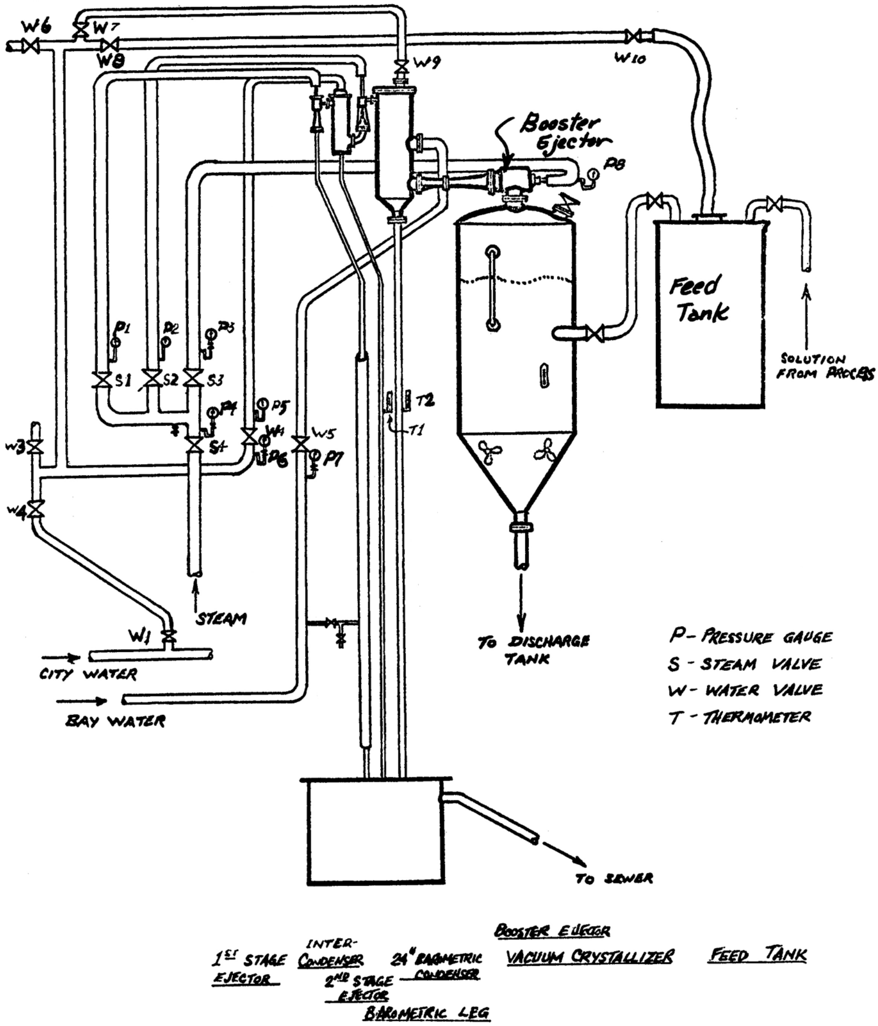

Figure 1-5 The vacuum crystallizer for Case #7.

Feedback for these cases is provided in Chapter 4.