6

DEVELOPMENT OF WORKING HYPOTHESES

6.1 INTRODUCTION

The title of this chapter requires some explanation. Dictionaries define a hypothesis as “a theory needing investigation” or “a tentative explanation for a phenomenon used as a basis for further investigation.” A working hypothesis is just that: It is a tentative explanation that can be used to investigate a problem further. This book does not deal with the multitude of methods that can be used to generate potential working hypotheses. Many of these methods put almost complete emphasis on accurate problem statements. The implicit assumption is that if the problem can be defined in sufficient detail then the problem solution will be apparent. In complex process plants, multifaceted problems can rarely be solved through this simple approach.

What is presented in this chapter is an approach for the development of theoretically sound working hypotheses based on careful consideration of a series of questions. These questions will require an analysis of the data in an introspective fashion. It is highly unlikely that the approach described in this chapter will provide only one possible problem solution. Thus, this and subsequent chapters also deal with ways in which the large number of possible working hypotheses can be narrowed down using logic and, most importantly, one’s technology training.

Problem Solving for Process Operators and Specialists, First Edition. Joseph M. Bonem.

6.2 AREAS OF TECHNOLOGY

As indicated earlier, there are two types of technologies utilized in process plants. These are process-related technologies and equipment-related technologies.

Process technologies are technologies that deal with a specific process. Examples of these include a polymerization process, an isomerization reactor process, and a distillation process. The process-specific technologies may include items such as reaction rate kinetics, polymer product attributes, or relative volatility data. Each of these processes will have specific technology details which must be well known and understood by the problem solver before he attempts to do any process-technology-related problem solving.

Equipment-related technologies are technologies that are valid for any specific piece of equipment, regardless of the process technology in the facility in which it is being used. Examples of these are details and calculations associated with pumps, compressors, and distillation towers. In addition, most kinetically limited processes (e.g., heat transfer) can be generalized in terms which will allow a hypothesis to be developed regardless of the specific technology. This approach to kinetically limited processes is described in detail in Chapter 9.

6.3 FORMULATING HYPOTHESES VIA KEY QUESTIONS

The primary purpose of Chapters 7 through 10 is to demonstrate how to use the five-step problem-solving procedure discussed in Chapter 3. The other equally important parts of this procedure, having a daily monitoring system and determining the optimum technical depth, were adequately covered in Chapters 3 and 4.

The emphasis in this chapter is on formulating and verifying theoretically sound working hypotheses. Formulating theoretically sound working hypotheses deals with an in-depth thought process that requires the problem solver to utilize his engineering training to develop a hypothesis. The in-depth thought process is rarely done in meetings. It often requires data analysis, literature research, and/or "one on one" discussions with experts in the field or those who can serve as a source of data. This in-depth thought process often involves consideration of the potential questions shown below to help define the cause of the problem. Examples are given for each question. These examples are not meant to be an inclusive list, but are given only to amplify the specific question. The questions are given in order of priority. Obviously this priority must depend on the specific problem and the specific process. These questions also assume that steps 1 (verify that the problem actually occurred) and 2 (write out an *accurate* statement of what problem you are trying to solve) have been completed.

1. Are all operating directives and procedures being followed? An inspection of operating conditions at most process plants will show that deviations from procedures and directives are occurring. These may or may not be related to the problem of interest. While it is important to verify that all procedures and directives are being followed, a small deviation should not be deemed to be the source of the problem unless there is a theoretically sound working hypothesis which explains how the deviation is causing the problem.
2. Are all instruments correct? Incorrect flow meters may result in reaction rates being different than expected, fractionation separation being below design levels, a pump or compressor appearing to be operating "off the curve," or failure to adequately strip an impurity from a polymer. A level instrument being wrong could result in reduced or increased reaction rate, which would manifest itself as a lesser or greater amount of reaction. Heat and material balances are exceptionally good tools and can often be used to answer this question.
3. Are laboratory results correct? If the problem under study is related in any way to laboratory results, confirming that the laboratory results are correct is a high priority. This confirmation can require review of the procedures as written, review of the procedures as performed, and review of the chemicals being used. For example, the results of an extraction procedure can be greatly altered if cyclohexane is used as the solvent when the procedure calles for the use of normal hexane.
4. Were any errors made in the original design? The high priority given to this possibility is due to the need to assess this question early in the problem-solving activity, prior to doing a large amount of work in other areas. This assessment can be made based on experience with the process and the length of time it has been in operation. The probability that original design errors are causing the operating problem decreases with the age of the process. However, one should not assume that just because a process has been in operation for several months that it is free of design errors. A new operating condition or new product grade may expose design errors that were not detected earlier. These design errors might be as small as a density being wrong on an instrument specification sheet to as large as incorrect tray selection for a distillation column. The assessment of potential design errors can only be made by either a detailed review of design calculations or by redoing these calculations. If it is necessary to review or redo design calculations, the process operator may need to obtain assistance from an expert skilled in this area.
5. Were there changes in operating conditions that occurred at the same time the problem began? These changes in operating conditions may immediately result in the observation of a process problem. However, the most likely scenario is that everything appears normal when the

changes are first made. However, at some later point in time there will be a small change in another variable and the problem becomes noticeable. An example of this might be a reduction in the operating temperature of an exothermic reactor in winter. After the reduction in temperature, all control systems appear to be operating normally. However, temperature control is impossible as the outside temperature and, hence, cooling water temperature increases with spring conditions. If the process being investigated is integrated with other processes (e.g., in a refinery or chemical plant complex), it will be desirable to also investigate operating condition changes in these other processes.

6. Is fluid leakage occurring? The term "fluid leakage" covers such areas as leakage through heat exchanger tubes, leakage across isolation valves, and leakage through control valves. Leakage can cause reaction rates to be lower than desired if the leaking component is an impurity. Leakage can also cause an apparent loss of fractionation efficiency or an apparent loss of pumping or compression efficiency. The potential for leakage can be determined by a flow sheet review, determination of pressure flow potential using measured pressures, and, in some cases, detailed calculations of control valve clearances.
7. Has there been either normal or unusual mechanical wear or changes that could impact performance? Erosion of wear rings or failure of check valves can greatly affect the performance of pumps and compressors. The performance of distillation columns can suffer due to the failure of a single tray segment. Unusual mechanical wear will often be caused by a large process upset. Mechanical changes might occur that would affect the process performance. For example, a change in the composition of material used in a mechanical seal might result in decomposition of the seal and contamination of a product.
8. Is the reaction rate as anticipated? At times, undesirable reaction rate is the problem . However, there are also times when an excessive amount of reaction or a lack of reaction is the cause of the problem. For example, alumina desiccant is known to have catalytic properties. The catalytic properties can usually be mitigated by operating techniques. However, if a batch of alumina desiccant has exceptionally high catalytic activity, the normal compensatory operating technique may not be adequate. This may cause problems in the process that can be traced back to the specific batch of alumina.
9. Are there any adverse reactions occurring? Adverse reactions are always a potential problem when dealing with reactive chemicals. The presence of solids in a distillation column that purified a diolefin, such as butadiene or isoprene, might be traced to small quantities of oxygen that entered the process from inadequately purged storage vessels and then catalyzed the reaction of the diolefin to form a polymer. Another example is the utilization of aluminum metal in an analyzer sample

system in which chlorides and olefins are present. The chlorides would react with the aluminum to form aluminum chloride, which would then cause the olefin to polymerize to an oily material and foul the analyzer. The trays in a distillation column might become plugged due to solids formed by the unexpected presence of water.

10. Were there errors made in the construction of the process? Construction errors are treated as a low priority simply because they almost always involve a unit shutdown or elaborate, noninvasive techniques to inspect potential problems. However, these errors do occur. Examples of construction errors are debris left in vessels or piping, improper leveling of distillation trays, beveled orifice meters installed backwards, failure to complete the cutting of a "hot tap" so that the flow path is greatly restricted, and installation of an incorrect pump impeller.

This list is meant to serve as a possible checklist that can be used to develop hypotheses. It is not meant to be an all-inclusive list. Certainly the priorities will change depending on the specific process and status of the process. However, it is believed that this approach can be effective in developing sound hypotheses.

While the crux of this book is directed toward equipment-related technologies, this approach to developing working hypotheses can be applied to process technologies as well.

6.4 BEAUTY OF A SIMPLIFIED APPROACH

The problem solver will often be tempted to invent a very complicated theory to explain observations that he does not fully understand. Generally, this will be counterproductive. A simple theory will often lead to a problem solution that is easier to execute and more effective. Over 100 years ago, the physicist Ernest Rutherford commented, "A theory that you can't explain to a bartender is probably no good."

A real-life example of this concept is found in the history of the Panama Canal. Yellow fever and malaria were serious problems which claimed many lives, especially during the French period of canal building. Since the worst epidemics seemed to start during the rainy season, the initial theory was that these diseases were caused by mysterious vapors which formed and came out of the swamps during the rainy season. This complex theory provided essentially no problem solution. Prior to the American construction of the canal, Dr. Walter Reed and his coworkers in Cuba had developed a simple competing theory to the "swamp theory." They theorized that yellow fever was spread by the Stegomyia mosquito. In addition, they discovered that this mosquito would only lay eggs in clean water held in an artificial container located in or near a building occupied by humans. With this relatively simple theory, problem solutions became apparent. This allowed the yellow fever threat in Panama to be greatly mitigated and was one of the keys for successful completion of the Panama Canal. Similar approaches were developed to mitigate the malaria threat.

6.5 VERIFICATION OF PROPOSED HYPOTHESES

In addition to the technique described above, there are multiple alternative problem-solving techniques touted throughout the industrial world. All of them involve developing theoretically sound working hypotheses. These alternative techniques also put emphasis on maximizing the number of possible hypotheses, based on the desire to not overlook any possibility. The techniques are of value for generating possible hypotheses; unfortunately, they often result in the assumption that a problem solution that seems logical is also technically correct. This is not always so. The process by which to verify a proposed working hypothesis is a procedure wherein the hypothesis is carefully examined, using the best available techniques. This verification process can rarely be done without calculations. For example, the hypothesis of an operator that the restriction to the flow of a liquid in a 4-in line is due to a short section of 2-in pipe may or may not be technically correct. It can only be assessed as a theoretically sound working hypothesis by calculations. The input of the operator is very valuable, since this detail might have been overlooked. However, his conclusion is likely erroneous.

Regardless of how hypotheses are developed, they will require verification. It is imperative that the problem solver use his training and calculations to eliminate the hypotheses which are not theoretically correct. These required calculations are part of step 3 (develop a theoretically sound working hypothesis that explains the problem) or step 4 (provide a mechanism to test the hypothesis). Regardless of whether they are included in step 3 or step 4, the calculations should be done before proceeding with a plan for a plant test or operating changes.

The problem solver is often limited in his problem-solving ability by the lack of proven industrial calculation techniques. For example, pragmatic utilization of pump curves is not taught in the academic world and may not be well understood by process operators and technicians. However, it is exceptionally important in industry. To aid the problem solver, Chapters 7–13 contain hints and useful industrial calculation techniques and approaches. These sections will not include of all the possible technology and knowledge associated with various types of equipment, but are meant to be a summary of valuable techniques and knowledge for the process operator or specialist with plant problem-solving responsibilities.

Rather than discussing specific unit operations, the approach of this book is to discuss formulation of working hypotheses in the following four areas:

- Prime Movers (pumps and compressors)
- Staged Processes (towers)

- Kinetically Limited Processes (heat transfer, reaction, drying)
- Unsteady State Processes

It is recognized that most operating companies have technical manuals that describe how to design particular pieces of equipment. These manuals are usually voluminous and are aimed at design as opposed to problem solving. As such, the problem solver does not often use them. In Chapters 7–10, an attempt is made to reduce the important equipment concepts to those that are required to solve problems. The judgment as to what should be included in these concepts is obviously informed by the author's own experience. An attempt has been made to cover a broad spectrum of process equipment. If a specific type of equipment is not mentioned, there will be similar equipment described in sufficient detail to allow one to formulate a working hypothesis for the equipment.

6.6 ONE RIOT, ONE RANGER

The Texas Rangers are the oldest law enforcement group with statewide jurisdiction on the North American continent. According to Texas folklore, in the late 1800s there was a small Texas town in which a large riot was imminent. The town had limited law enforcement resources, so they requested that the governor of Texas send a troop of Texas Rangers to quell the riot. When the train arrived, carrying what the townspeople thought would be a troop of Rangers, only one person emerged from the train. When the townspeople expressed shock, the Ranger's reply was, "One riot, one ranger."

While it is true that a committee will always have more knowledge of facts than any single individual, the most effective problem solving is accomplished when one person has the responsibility to solve the problem and simply uses input from others. This single individual in process plants is almost always a chemical engineer, a process engineer, or an individual acting in the one of these roles. This individual can also be a process operator or specialist who has been assigned the responsibility to obtain a solution to a chronic problem. It is extremely important for him to bridge the chasm between his own training/experience and that of others who may have important knowledge or data that will help solve problems. For example, very few process operators have detailed knowledge of mechanical seals. However, mechanical seals are an integral part of a centrifugal pump. Therefore, when a problem solver is working on a centrifugal pump problem, it is likely that knowledge of mechanical seals will be required. This knowledge can best be obtained from discussions with mechanics and/or mechanical engineers.

An example of the need to bridge the chasm between engineering disciplines was a chemical engineer who was asked the question "Is it okay to operate these two identical centrifugal pumps in parallel to obtain increased capacity?" His reply was "I don't know; that is an equipment question." In fact, the chemical engineer or process specialist will be the individual who has the necessary knowledge of process conditions to answer the question. He will have to conduct a more detailed analysis and develop a better understanding of centrifugal pumps to finalize the answer to the question. For example, he would have to develop understanding of the following.

- Running pumps in parallel involves determining the exact location on the pump curve (flow rate), determining the capability of the control system to handle the increased pressure drop, and determining the minimum flow that might be encountered during parallel pump operation. These are clearly more than "equipment questions."
- Running pumps in parallel at low flow rates can sometimes result in one of the pumps operating in a "blocked in" condition. If this condition occurs, one of the pumps is pumping the full process flow while the output from the other pump is very little. This "blocked in" operation could create a serious operation and safety problem. This condition could occur even though the pumps are identical, due to different clearances on the wear rings. This clearly requires consultation between various engineering disciplines.
- Although it is a little known fact, centrifugal pumps often experience a loss of stability similar to that which occurs in centrifugal compressors operating at lower flow than the surge point. If a centrifugal pump is operated at flows below this stability point, serious vibration can occur. The chemical engineer would certainly have to depend on another discipline to determine the stability limit.

The primary point of this discussion is that the process operator acting as a chemical engineer and being the "problem solver" in a process plant must know about or obtain knowledge of the equipment that is involved in the problem he is solving. He will often be required to determine why the piece of mechanical equipment does not have as much capacity as it should, rather than just saying "It is not operating at design capacity."

Similar points could be made in the areas of process chemistry. A process operator serving as a problem solver must obtain the necessary knowledge of the process chemistry in order to formulate theoretically sound, working hypotheses. Once the process chemistry is understood, the same five-step procedure can be used to solve process chemistry-related problems as well as process equipment problems. Time spent with a chemist familiar with the specific process technology chemistry will greatly aid in formulating correct working hypotheses. This need will be obvious in a process where reactors are utilized. However, in almost any process, the possibility for reaction exists. Ignoring the need to completely understand process chemistry can lead to the formulation of incorrect hypotheses. For example, in a polymer plant, a process engineer developed a hypothesis that the polymer was turning a light shade of pink due to the presence of iron complexes caused by corrosion. A more detailed analysis with a process chemist revealed that one of the additives being used was also a pH indicator, and that the pink color was due to the slight basicity of the polymer.

In spite of the emphasis on the "one riot, one ranger" approach above, the problem solver should never assume or pretend that he has all the knowledge necessary to work the problem. A truly effective problem solver will know and admit his limits. He will then look for help in areas outside of his knowledge. However, he will seek this knowledge in order to apply it to the current problem, as opposed to trying to reassign the problem to someone else.