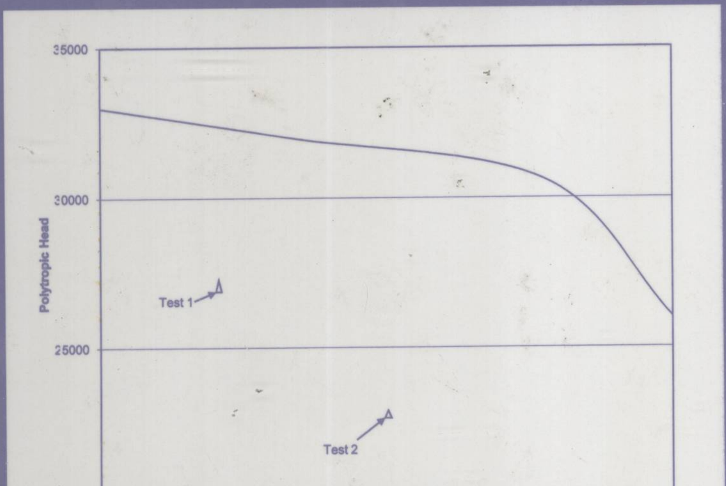
JOE M. BONEM

PROCESS ENGINEERING PROBLEM SOLVING

Avoiding "The Problem Went Away, But It Came Back" Syndrome



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PROCESS ENGINEERING PROBLEM SOLVING

This book is an attempt to both leave a legacy and to provide assistance for those starting or in the early stages of a career in engineering.
The efforts in putting this book together are dedicated to:
My Wife, Diane, who managed to teach me through words and examples that "people are more important than things".
Our Children, Mike, Tracey and Amy, who during their teenage years, taught me the value of just listening rather than always trying to solve problems.

PREFACE

The subtitle of this book comes from my experience of listening to frustrated engineers describe problem solving in modern complex process plants. I have often heard the expression—"We did a couple of things and the problem went away". As I heard this, I normally said either to myself or aloud—"If you don't know why it went away, there is a high probability that it will come back".

During years of experience, I observed well-trained chemical engineers that had graduated in the upper part of their class having difficulty solving plant technical problems. I concluded that often these well-trained engineers were not really trained in subjects that would allow them to solve real-life plant process problems. They had minimal training in problem-solving techniques and much of their academic training was not directed at pragmatic solutions. For example, the academic world was training in thermodynamics, but not in how does the theory apply to reciprocating or centrifugal compressors. With this limited amount of training in approaching real-world problems, the process engineer would often settle for a problem-solving approach based on logic with no calculations or even worse simple intuition. In addition, the pressures of a real-life problem-solving environment often caused him/her to take the approach of "trying something even if it doesn't work". Management rarely indicated that the engineer should take the time to make sure that the problem was worked correctly. Many times the belief of an operator and/or mechanic was taken as being the correct problem solution simply because the engineer did not have a good framework to develop any other possibility. Since the graduate engineer and operator now seemed to agree, management felt comfortable in implementing the "joint recommendation". Often times these solutions failed. Even worse, the results of the attempted solutions were not documented and there was a strong possibility that the same problem solution would be tried again at a later date.

In an effort to mitigate the failure to solve industrial problems, a new series of techniques were developed that called for using teams to solve problems via interactive "brainstorming" approaches. I observed that the advantages of these teams were that they often brought a tremendous amount of data to bear on the problem and that they generated a long list of *possible* hypotheses.

However, this approach was no more effective than the previous ones. The reason why this large amount of data failed to produce effective solutions was that there was no systematic analysis of the data. In addition, there was no stipulation that the possible hypotheses had to be theoretically possible. Thus, theoretically impossible hypotheses were treated with the same validity as the theoretically possible ones. The most likely outcome of such brainstorming sessions was that the solution with either the most votes or the loudest proponents was adopted as the recommended approach.

In spite of these less than perfect approaches, industrial problems are being solved by intuitive, logical approaches and/or brainstorming that do not involve calculations and/or data analysis. Most of these problems are being solved by experienced engineers and/or operators. However, these problems are generally not complex or chronic in nature. It is the chronic problems and/or those requiring an engineering analysis that this book addresses. In addition to the current situation, as the "baby boomers" age and retire, the experience that is often of value in problem solving is not being replaced. Thus, a more structured approach will become even more important in the next decade.

I cannot claim that the techniques discussed in this book will allow the process engineer to achieve perfection in the area of problem solving. However, I can say that these techniques have worked for me throughout a long career of industrial problem solving. The chemical engineering fundamentals discussed in the book are presented from the perspective of the problem solver as opposed to the perspective of a process designer or the perspective of one in the academic world. There are shortcuts and simplifying assumptions that are used. These may not be theoretically precise, but they are more than adequate for problem-solving activities. There are without a doubt additional chemical engineering fundamentals that should be covered. However, I have selected those areas that I felt would be of most value to the industrial problem solver.

My industrial experience indicates that there are three requirements to successfully solving complex problems. They are as follows:

1. You must have verifiable data.
2. You must use a structured problem-solving approach that includes a statement of what problem you are trying to solve. This requires rigid discipline. As discussed in Chapter 1, we often fail at simple problem solving because we tend to rely on intuition or experience-based solutions as opposed to a more rigorous structured problem-solving approach.
3. You must use sound engineering skills to develop a *simple* working hypothesis.

If any one of these three is absent, unsatisfactory results will likely result. For example, a logical solution to a problem is of no value if it is not based on sound data or if the conclusion violates a fundamental premise of engineering. Conversely, a sophisticated computer simulation program is of little value unless it is directed toward solving the correct problem.

Multiple surveys and interviews throughout the United States have listed "problem-solving skills" and "vocational-technical skills" in the top 10 skills that employers wish their employees had. This book deals with these two skills as follows:

1. The three essential problem-solving skills (Daily Monitoring System, Disciplined Problem-Solving Approach, and Determining Optimum Technical Depth) are discussed and guidelines are provided for successful implementation of each of these.
2. Vocational-technical skills are enhanced by equipment descriptions, helpful hints and practical knowledge that will expand the problem solver's academic training. The helpful hints and practical knowledge include calculation techniques that are presented without lengthy derivations and proofs.

Several example problems are included throughout this book in order to illustrate the concepts and techniques discussed. Some of the example problems are included in the chapters devoted to specific aspects of process engineering. The remainder are included in Chapter 13. This chapter is meant to deal with a series of problems that involve multiple aspects of process engineering problem solving. The problems in the book are for the most part real-world problems. The failures and successes described actually occurred. The problem-solving techniques described in this book were responsible for the successes. Failures were often due to not using the techniques described. Occasionally, fictitious problems are created to help illustrate important concepts or calculation techniques.

The English set of units has been used throughout the book. The English units and their abbreviations are described at the end of each chapter. A table of conversion factors to scientific units is provided in Appendix 2.

Throughout the book, I have used the term "problem solver" to mean the individual with direct responsibility for solving the problem under consideration. I have also used the masculine pronoun "he" knowing full well that there are talented female problem solvers as well.

I have often been asked about the utilization of the principles described in this book by other engineering disciplines or by operators/mechanics. It is my firm belief that the problem-solving principles (Daily Monitoring System, Disciplined Problem-Solving Approach, and Determining Optimum Technical Depth) described in this book could be used by other engineering disciplines or operators/mechanics. A non-process engineer could not be expected to have the academic skills to formulate a full range of process hypotheses. However, he will have the skills to formulate hypotheses associated with his particular discipline. In addition, because of the pragmatic approach used in the book, it is likely that a non-process engineer or an operator/mechanic could readily learn how to do the calculations required to formulate some theoretically correct hypotheses.

Joe M. Bonem

CONTENTS

1

INITIAL CONSIDERATIONS

1.1 INTRODUCTION

Problem solving is an area that is found throughout all activities of daily life. Problem solving tends to take place in two mind modes. There is the intuitive or instinctive reactionary mode, which has also been called "gut feel". Then there is the methodical reasoning approach, which is usually based on theoretical considerations and calculations.

Either of these approaches has its place in real-world problem-solving activities. The intuitive reactionary person will respond much faster to a problem. The response is usually based on experience. That is, he has seen the same thing before or something very similar and remembers what the problem solution was. However, if what is occurring is a new problem or is somewhat different, his approach may well lead to an incorrect problem solution. The methodical reasoning person will not be able to react to problems quickly, but will usually obtain the correct problem solution for complicated problems much faster than the intuitive reactionary person who must develop several aborted "gut feel" solutions.

An example of how two people with these different mind sets will react can be found in the most unlikely places. For example on a golf course, the cry of "Fore" will illicit different responses. The person responding based on intuition or instinct will immediately cover his head and crouch. This will reduce the probably that the errant golf ball hits a sensitive body part. The person responding based on methodical reasoning will begin to assess where the cry came from, where the ball might be coming from and reach a conclusion where it might land. Obviously in this case, reacting based on intuition or instinct is a far superior mode of operating. There could be many more examples from the sports world where reacting in an intuitive fashion yields far superior results than reacting in a methodical reasoning manner. *However*, essentially all of these examples will be experienced based. People that are reacting successfully in an intuitive mode know what to do because they have experienced the same or very similar situations.

Similar things happen in industrial problem solving. Experienced people (engineers or operators) react instinctively because they have experienced similar events. These operators or engineers do an excellent job of handling emergency situations or making decisions during a start-up. As a rule, the person that tends to respond based on methodical reasoning and calculations rarely can react fast enough to be of assistance in an emergency or if quick action is required in a start-up situation. The exception to this rule is the engineer that has designed the plant and has gone through calculations to understand what will happen in an emergency or start-up. In effect, he has gained the experience through calculations as opposed to actual experience.

The experience necessary to conduct problem solving in the real world does not always exist. In addition, while the need for quick response when solving industrial problem is real, there is not always an emergency or crisis need to take immediate action. Thus, the methodical reasoning approach is often the desirable mode of operating. The three components of this methodical reasoning approach are:

1. A systematic step-by-step procedure. This includes the three essential problem-solving skills (Daily Monitoring System, Disciplined Problem-Solving Approach, and Determining Optimum Technical Depth).
2. A good understanding of how the equipment involved works.
3. A good understanding of the specific technology involved.

Before discussing problem solving in industrial facilities, two examples from everyday life are discussed. It often aids learning, to discuss things that are outside the scope of the original thrust of the teaching. The two examples from everyday life discussed below will be helpful in understanding the difference between intuitive problem solving and those based on methodical reasoning.

1.2 AN ELECTRICAL PROBLEM

While trimming bushes with an electric hedge trimmer, a laborer accidentally cut the extension cord being used to power the trimmer. He had been using an electrical outlet in a pump house located approximately 70 feet from the main house. The only other use for 110-volt electricity in the pump house was for a small clock associated with the water softener. The laborer found another extension cord and replaced the severed cord. However, when he plugged it in and tried to turn on the hedge trimmer, it did not have any power. He then had to report the incident to the homeowner. The homeowner checked the panel mounted circuit breakers. None of them appeared to be tripped. However, to be sure he turned off the appropriate circuit breaker and reset it. However, power was still not restored to the outlet in the pump house. To make sure that the replacement extension cord was not the problem, the homeowner plugged another appliance into the electrical outlet in the pump house. It did not work either. The homeowner then concluded that the electric outlet had been "blown out" when the cord was cut. He replaced the electric outlet. However, this still did not provide power to the equipment. When the homeowner rechecked the circuit breaker, he noticed that a GFI (Ground Fault Indicator) in a bathroom was tripped. Resetting this GFI solved the problem.

While the homeowner believed that in this particular house every GFI protected a single outlet, it is not unheard of to protect more than a single outlet with a GFI. It seemed surprising that the GFI in a bathroom also protected an outlet in the pump house 70 feet away. The homeowner then recalled that at some point in the past, he had noticed that the small clock in the pump house was about 2 hours slow. This clock was always very reliable. In retrospect, he remembered that at about the same time that the clock lost 2 hours, this particular GFI had tripped during a lightning storm and had not been reset for a few hours. Thus, it became obvious that the accidental cutting of the extension cord had caused the GFI to trip rather than tripping the circuit breaker or "blowing out" the electrical outlet. The failure to correctly identify the problem cost the homeowner a small amount of money for the electrical plug and a significant amount of time to go to town to purchase the plug and then install it.

Note that the homeowner's intuitive approaches were all real possibilities. That is, the circuit breaker could well have tripped, the replacement extension cord could have had an electrical break in it, or the electrical outlet could have failed when the original extension cord was cut. His problem solving just did not go into enough detail to solve the problem quickly. Several lessons can be learned from this experience. While it seemed to be a simple problem that could be easily solved based on the homeowner's experience, the intuitive approach did not work. A more systematic approach based on methodical reasoning might have improved results as follows:

- Consideration would have been given to the possibility that GFIs can protect more than one plug. The distance between the GFI and the electrical outlet would not be a consideration. The homeowner did not fully understand the technology.

- A voltmeter would have been used to check that power was available coming to the electrical outlet. If power was not available coming to the outlet, the "blown plug" hypothesis would be invalid. A systematic approach was not used.
- In addition, a systematic approach would have raised the question of whether the clock losing 2 hours could be related to the lack of power at the electrical plug.

1.3 A COFFEEMAKER PROBLEM

A housewife experienced problems with a coffeemaker overflowing about half of the time when she made either a flavored or decaffeinated coffee. The coffee and coffee grounds would overflow the top of the basket container and spill all over the counter. The coffeemaker performed flawlessly when regular coffee was used. A sketch of the coffeemaker is shown in Figure 1-1. When the coffeemaker is started, water is heated and the resulting steam provides a lifting mechanism to carry the mixture of water, steam and entrained air into the basket where the ground coffee resides. The hot water dissolves the coffee and it flows into the carafe. The coffeemaker is fitted with a cutoff valve that causes the flow out of the basket to stop if anyone pulled the carafe out while coffee is still being made.

The housewife asked her husband, a graduate engineer, to determine what was wrong. The housewife's engineer husband examined the problem by first convincing himself that his wife was following directions when it came to making the coffee. He then carefully examined the equipment especially the

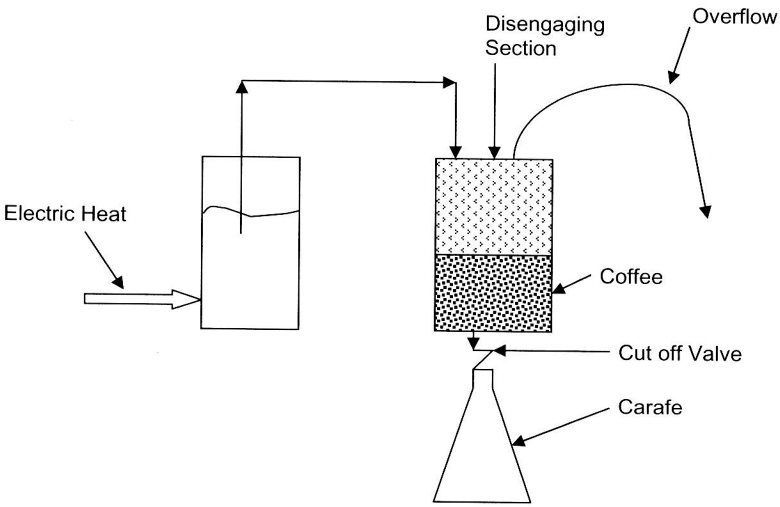

Figure 1-1 Coffee pot schematic.

cutoff valve. He concluded that somehow the cutoff valve was restricting the liquid flow whenever decaffeinated or flavored coffee was being made. That is, the incoming flow of hot water and steam was greater than the flow out of the valve. This would cause the level in the container to build up and run over. The problem solution seemed relatively simple. He removed the valve and made a sign that said "Do not remove carafe until coffee is finished brewing". He felt a surge of pride in not only solving the problem, but that he prevented a future problem by providing instructions to prevent someone from pulling out the carafe. The next time that one of the suspect coffees was made, the container did not overflow. He then announced that the problem was solved.

Unfortunately, the glow of successful problem solving did not last long. The next time that flavored coffee was made the problem reoccurred—that is, the coffee and grounds overflowed the top of the basket container. The engineer then began a more detailed investigation of the problem including understanding the technology for making flavored and decaffeinated coffee. He discovered that when decaffeinated coffee was being made, a surface-active material was utilized. This surface-active material was mixed with the coffee to extract the caffeine. He extrapolated from this and theorized that when flavored coffee was being made, a surface-active material was used to evenly distribute the flavor to the coffee. Once he understood the difference in the coffee-making processes, he theorized that residual amounts of the surface-active material being left on the coffee reduced the surface tension of the hot water and coffee, and allowed it to foam up in the container and out over the sides onto the counter.

Since the amount of residual surface-active material would vary slightly from batch to batch, it was theorized that only the batches of either flavored or decaffeinated coffee that contained greater than a critical level would cause an overflow. After studying this theory, the engineer decided that the problem solution would be to obtain a coffeemaker that had a basket container with a different design. The problem coffeemaker had a small cylindrical shaped basket. A new coffeemaker with a large conical design basket was purchased. The comparison of the two baskets is shown in Figure 1-2. It was theorized that the large conical design would provide a reduced upward velocity of the foaming material and this would allow more disengaging of the vapor trapped in the foam. The purchase of this coffeemaker eliminated the problem completely.

Several lessons can be learned from this problem-solving exercise. The intuitive hunch that coffee was not flowing through the valve as fast as hot water was coming into the basket made logical sense. However, no logical explanation was provided for why this only happened with flavored or decaffeinated coffee. Any theory that has the phrase "for some reason" is suspect and is an indication of an incomplete problem analysis. An incomplete problem analysis almost always has a portion of the analysis that is very logical. However, it is imperative that the entire analysis be logical. Another error was

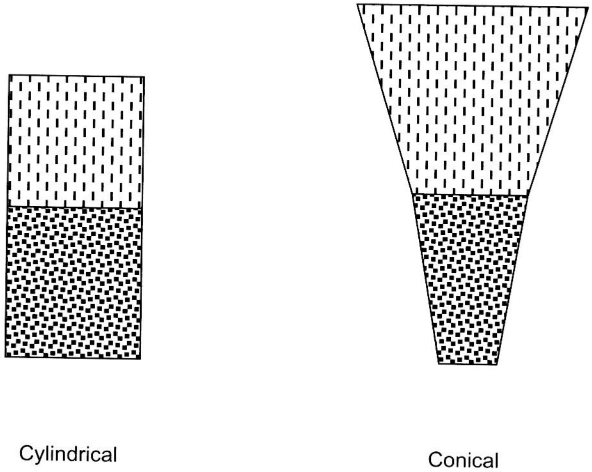

Figure 1-2 Basket comparisons.

that in formulating the hypothesis, the engineer assumed that only liquid water and solid coffee existed in the container. He overlooked the fact that steam vapors and entrained air were always carried into the container with the hot water. The presence of steam and air would provide a mechanism for creating a frothy mixture. The example also illustrates the need for the following:

- A systematic approach—A systematic approach as will be described later in this book would have eliminated the incomplete hypothesis that suggested the outlet valve was a restriction on only certain grades of coffee.
- A good understanding of how the equipment works—If the engineer had understood how the coffeemaker worked, he would not have assumed that only a liquid was present along with the coffee in the container. He would have recognized that both steam and air were carried over into the container along with the hot water.
- A good understanding of the technology involved—The fact that decaffeinated and flavored coffee performed differently than regular coffee should have been an indication to the engineer that he needed to examine the difference in the coffee-making technology.

These relatively simple examples of how successful problem solving requires a more detailed analysis than simple logic and/or intuition are meant to set the stage for the next chapter which deals with limitations to industrial problem solving. While industrial problems are almost always more complicated than those described in this section, the same problem-solving approach needs are present.

2

LIMITATIONS TO PLANT PROBLEM SOLVING

2.1 INTRODUCTION

While later chapters will consider the engineering approach to problem solving, any book dealing with plant problem solving will touch on the question—"Is problem solving really engineering?" If one defines engineering as dictionaries do—"The science of making practical application of knowledge in any field", we must conclude that problem solving is truly engineering. Often engineers may conclude that problem solving is not truly engineering because of the following:

- Engineering is defined in such narrow terms that only "design work" appears to be engineering.
- Intuition and "gut feel" have replaced thorough analysis as a preferred tool for problem solving.
- Considerations of "optimum technical depth" are not well understood.

It is also important to understand why a course in engineering problem solving is of value. In a typical industrial problem, a customer is unhappy with the appearance of the plastic pellets being received from his supplier. Specifically, the pellets have visual discontinuities that he describes as "voids". A simplified statement of the problem is shown in Figure 2-1.

As shown in this figure, the process where the pellets are manufactured consists of two sections (polymerization and extrusion). A strong correlation

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