HOW TO LIE WITH ENGINEERING GRAPHICS

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The essence of engineering is truthfulness. If we are truthful in all of our conduct, then we are most likely acting ethically. While this may seem like an oversimplification, the idea of truthfulness certainly addresses the central issue of engineering communication. The negative side of truthfulness is a bit more ethically complicated. What does it mean to not tell the truth? Are all non-truths lies? Are all lies unethical?

In engineering communication, as in all communication, there are two basic types of non-truths: lies and deceptions. In both cases the intent is to have the recipient of the information draw a false conclusion from the available information. While both methods of eliciting false conclusions may be morally wrong, there is a well-defined operational difference between a lie and a deception.

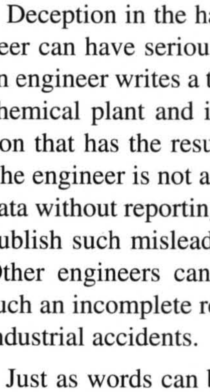
A "lie" is a categorical statement known by the teller to be untrue. An engineer who tells a client that the client's report has been mailed, for example, while knowing full well that it is still being prepared, is telling a lie. Most lies are verbal, but lies may also be told by body language, such as nodding the head, or by graphics when, say, some data points are intentionally omitted to "make the graph look better." Lying requires only that incorrect information is intentionally transmitted. If I say "I am ten feet tall," that is a lie, regardless of who I tell it to.

In contrast to a lie, a deception is an action that begins with a statement (verbal or graphical) that may be true, but the intention is for the listener or reader to draw a false conclusion. If an anxious client asks an engineer for the status of a report, the engineer can say that "it is essentially finished." The client might interpet this as meaning that it will be collated in time to be picked by by FedEx that afternoon, but the fact might be that not all of it has yet been written. If, by using such a phrase as "essentially finished," the engineer knows that he or she is creating a false impression (without overtly lying), he or she is guilty of intentional deception, and deception with an intent to mislead or obfuscate is not honorable behavior. If the client is savvy enough to ask what the engineer means by "essentially finished," the engineer has a chance to tell the truth or to lie.

Deception in the hands of a professional such as an engineer can have serious repercussions. For example, suppose an engineer writes a technical article about an explosion at a chemical plant and intentionally uses incomplete information that has the result of deceiving the journal readership. The engineer is not actually lying, but rather is using partial data without reporting that other data have been omitted. To publish such misleading information is unethical behavior. Other engineers can draw unwarranted conclusions from such an incomplete report and the result could be additional industrial accidents.

Just as words can be used to mislead a reader, unscrupulous or incompetent illustrators can distort engineering illustrations with both lies and deceit. Thus, we must judge engineering illustrations not only on the value of their information and on their appearance, but also on their integrity.

In most cases, graphics have a certain sacred value to engineers, and illustrations are seldom blatant lies. Few engineers and scientists will intentionally misplace a data point



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on a graph or add points without having the data. For this reason, most engineering readers place a great deal of weight and credibility on data points.

Sometimes, however, some researchers or practitioners fail to include all the relevant data points or will move data points to "improve" the graph. Occasionally, data points are so far off the line that the researcher is tempted to either discard them as "something went wrong here" or note them as "rogue points." There even exists a statistical test that can be used for removing (with full statistical justification) the data point from the graph. This is a risky business since the one "rogue point" may in fact have been an indicator of something very important and totally unexpected.

Fortunately, instances where engineers and scientists have used graphs for transmitting incorrect information (lies) seem to be rare, and in cases where there have been fabrications of data, the scientific community has properly condemned the actions. A much more insidious (and more common) miscommunication of graphical information is the use of illustrations for purposes of deception. Graphs don't have to actually lie to express incorrect information since it is the *perceived* information that matters. Most misleading illustrations are deceptions rather than lies. Such deception can be achieved by several unethical techniques, including optical illusion, inappropriate cause and effect, unwarranted visual embellishment, and misuse of data.

OPTICAL ILLUSIONS

Optical illusions in engineering drawing create misperceptions that can cause mistakes. Engineering drawings must not only be accurate, but they must also be perceived accurately by others. Our eyes can play tricks on us, and it is the responsibility of the communicator to minimize the potential for misperception.

Psychologists have identified at least five different visual illusions:[1]

1. Illusions of extent—the size or length is misjudged

2. Illusions of direction—the orientation of a line or figure is misjudged

3. Illusions of shape

4. Illusions of brightness

5. Illusions of motion

Figure 1 shows some examples of the first illusion—illusion of extent. In Figure 1A, the length of the straight line between the arrows is equal, but the optical illusion is that the lower one is longer. This same trick can be applied to space, shown in Figure 1B. Figure 1C shows that the outer circle of a concentric pair is underestimated while the inner circle is overestimated. Figure 1D shows that for two equal figures between converging lines, the one nearest the "vanishing point" is perceived as larger.

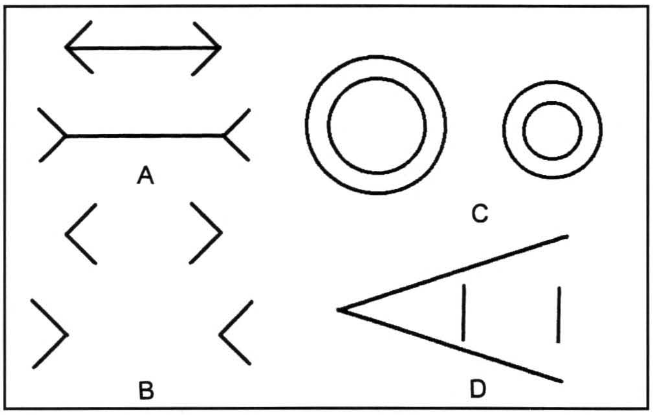

Figure 1. *Illusions of extent.*

Illusions of extent can be used to draw graphics that misrepresent the facts. Figure 2 is an example of such a misrepresentation. Drawing the bar graph inside diverging lines suggests a decrease that in fact is not true.

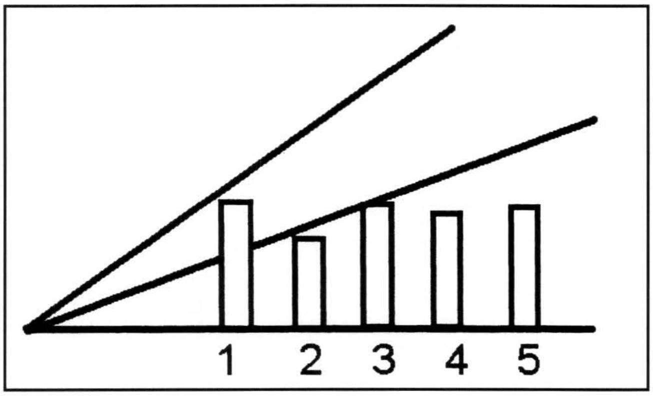

Figure 2. *Using illusion of extent to deceive the reader.*

Figure 3 shows several examples of the illusion of direction in which the orientation of a line or figure is misjudged. Figure 3A shows that although the two line segments intersecting the parallel line are actually on the same straight line, they do not appear that way to the eye. Figure 3B shows how the sequence of white and black squares can make the lines between them appear to bend. Figure 3C shows two parallel lines that certainly do not appear to be parallel.

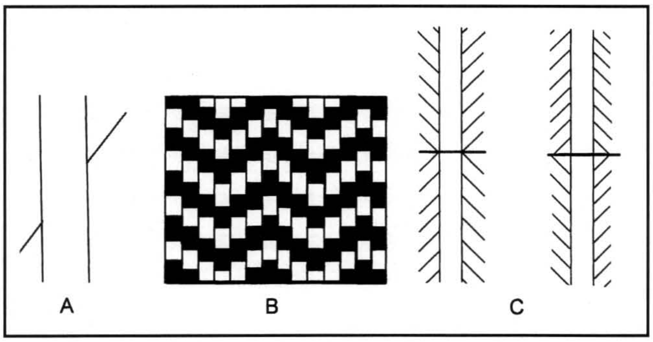

Figure 3. *Illusions of direction*

The illusion of direction can be used in a graphic as shown in Figure 4. Even though the two lines are parallel, the illusion is that the lines are diverging and the casual observer is left with the impression that the number of people smoking cigarettes has grown at a faster rate than the number of people not smoking.

Illusions of shape are illustrated in Figure 5. The straight lines on top of the pointed arch in Figure 5A appear to bend to make a sharp point. Figure 5B shows three arcs of equal sized circles. The more of the arc that is shown, the more the arc appears to curve. All arcs have, however, the same radius. Figure 5C is an amazing figure showing how the circle can appear to be distorted.

The illusion of shape can be shown by the embellished bar graph in Figure 6. Not only is the last bar fancied up, but the chevrons also give an optical illusion of fatness on top, suggesting growth that isn't there in reality.

Illusions of brightness can be illustrated by the block diagram in Figure 7A. If you look at the figure for a while, you will see darker spots in the white spaces at the corners of the black squares.

Illusions of motion are often used to trick the eye. Airplane pilots have long been aware of the apparent motion of spots of light during a dark night, called *autokinesis.* In one interesting experiment, the subjects were placed in a very dark room and asked to focus on a tiny spot of light on the far wall. They were told that the light would be moved to spell words and the test (they thought) was for them to try to read the words. All subjects read what they wanted to read, while in fact the light never moved!

Figure 7B shows an example of autokinesis. If you stare at the figure for a while, you will see swirling motion. Motion is optically created while the figure is obviously not moving.

IMPLIED CAUSATION

Another way graphics can deceive is by implying causation where none is warranted. Figure 8 shows the correlation between the rate of typhoid fever deaths and the fraction of the population with public water supplies. Such graphs have been repeatedly published by environmental engineers who want to convince the world that they have performed magnificently and should receive due credit for their efforts. There is no doubt that the construction of clean public water supplies helped reduce the typhoid death rate, *but this graph does not prove it.* An excellent correlation also results from plotting the reduction in the typhoid death rate and the decrease in the manufacture of buggy whips. The conclusion, if causation is mistaken for correlation, is that either buggy whips cause typhoid or the reduction in typhoid deaths resulted in the decrease in buggy whips.

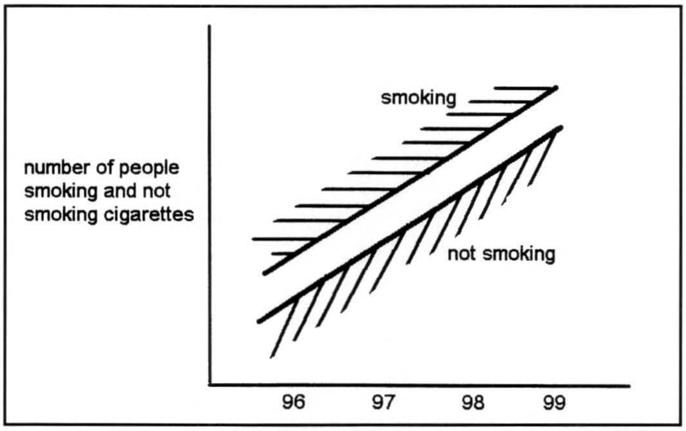

Figure 4. *Using illusion of direction to deceive the reader.*

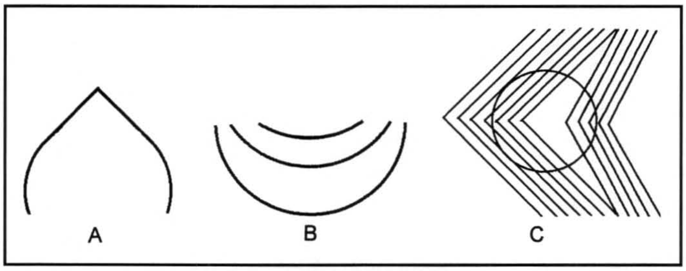

Figure 5. *Illusions of shape.*

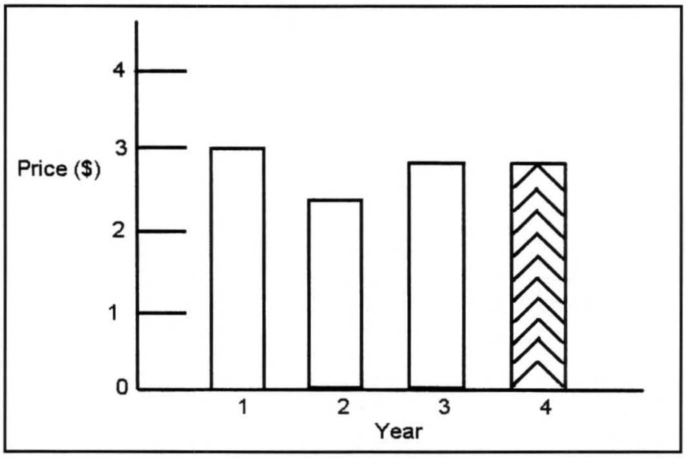

Figure 6. *Using illusion of shape to deceive the reader.*

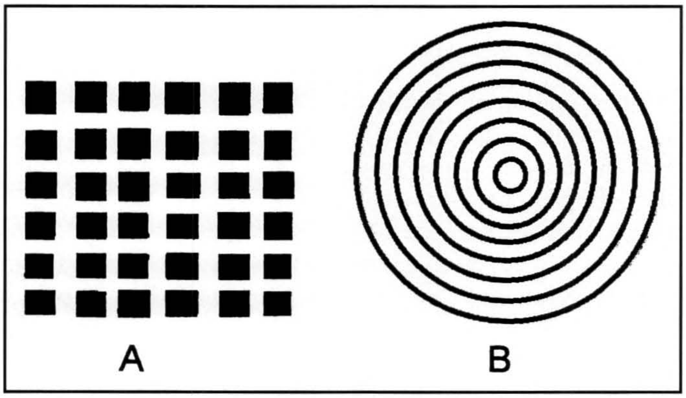

Figure 7, *Illusion of brightness and illusion of motion.*

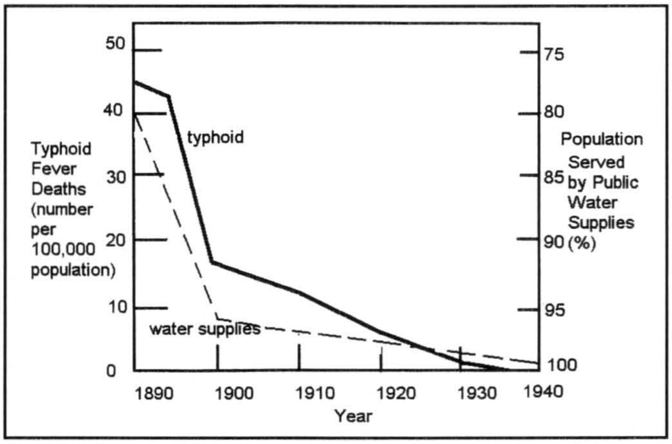

Figure 8. *Correlation between population with public water supplies and the typhoid fever death rate in the United States. (After Whipple and Horwood, from Fair, G.M., J.C. Geyer, and D.A. Okun,* Water and Wastewater Engineering, *John Wiley & Sons, New York, NY 1966).*

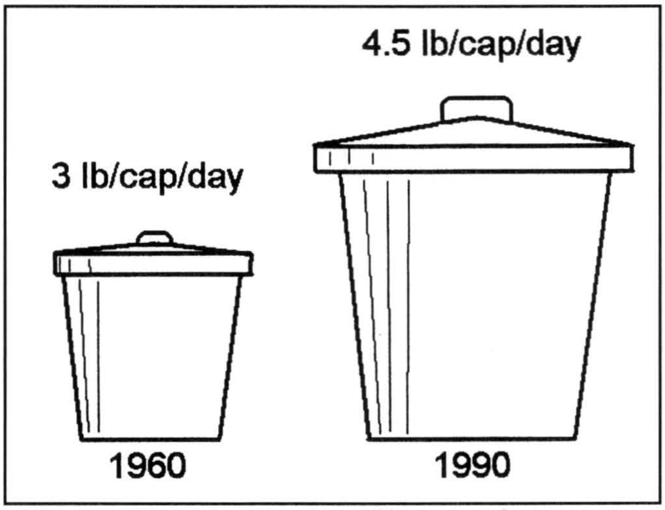

Figure 9. *Deceptive use of two-dimensional pictures to represent one-dimensional data.*

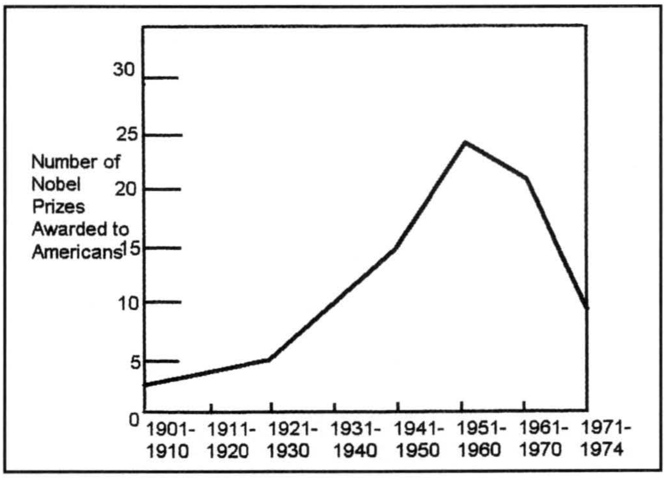

Figure 10. *Misleading line graph due to uneven scale. (National Science Foundation,* Science Indicators, 1974, *Washington, DC, 1976)*

VISUAL EMBELLISHMENTS

A third common source of misperceived (and thus unethical) graphics is the use of visual embellishments. One oft-used visual embellishment technique is the two-dimensional bar graph. A bar in a bar graph is one-dimensional, showing the quantity as its height. But the bar can also be shown as a two-dimensional picture. Figure 9 shows how trash cans represent the bars, but these are actually two-dimensional pictures. From this figure we see that even though 4.5 is only 50% larger than 3.0, the appearance is much greater since the reader sees the area of the trash cans, not just the height.

MISREPRESENTATION OF DATA

Some graphs are clearly intended to mislead. For example, Figure 10 shows a notorious graph that appeared in a government document arguing that the United States was losing its edge in science and technology since our share of the Nobel prizes seemed to have dropped precipitously. The truth is that the last data point (1971-1974) is the total number of Nobel prizes for only a *five-year* interval, whereas all the remaining points represent Nobel prizes received during *ten-year* intervals.

Some graphs deceive because the data are plotted cumulatively, and the reader is not sufficiently warned to interpret the graph in such a fashion. Figure 11 shows the use of various forms of power for electricity production. A quick glance suggests that nuclear power is the most important energy source and continues to provide the greatest share of electricity. The data in this graph are, however, plotted cumulatively so that the energy production from various sources is the difference between the adjacent lines.

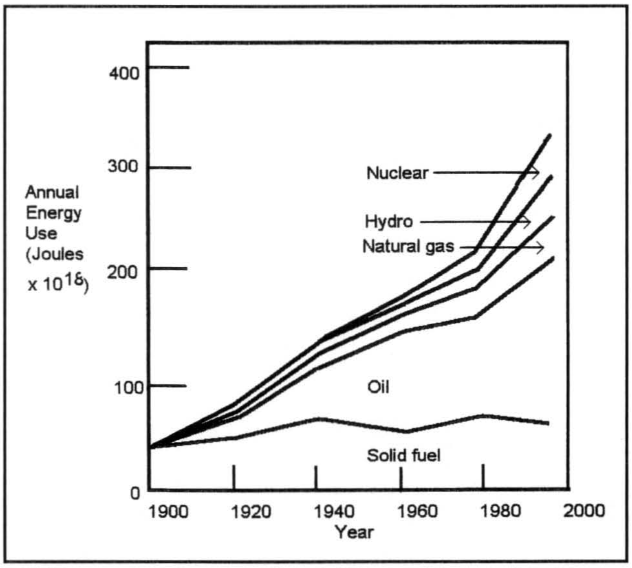

Figure 11. *An example of a deceptive graph where the data are summed.*

Broken scales can also convey misleading information. Broken scales occur either when an axis does not start at zero or when the scale is temporarily discontinued. Note how Figure 12A creates a mistaken impression by not starting at zero and thus conveys a very different impression from the more honest Figure 12B. Good practice requires that all broken scales be clearly indicated.

Sometimes it is possible to conceal data points in such a way as to make the rest of the data appear much more impressive, and thereby mislead the reader. Like Figure 13A, Figure 13B shows accurate points, but with the abscissa moved so that the points are concealed.

Sometimes the authors of a graph read more into the data than a reasonable person might. Figure 14A shows data used as the foundation for a complex theoretical model. Figure 14B shows the same data with the line as drawn by the authors. There is no reason to draw such a line—except that the model developed by the authors predicted that this would occur. The most that can be said in such cases is that the data certainly did not *dis*prove the model. Claiming that the data offer proof of the model is, however, unwarranted.

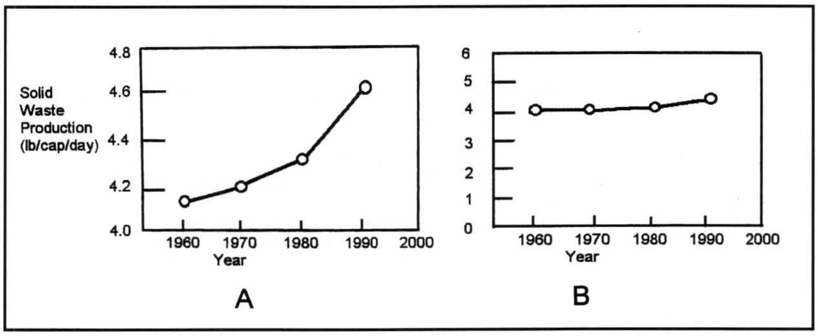

Figure 12. *Data as presented by the authors (A) and a more honest presentation without the broken scale (B).*

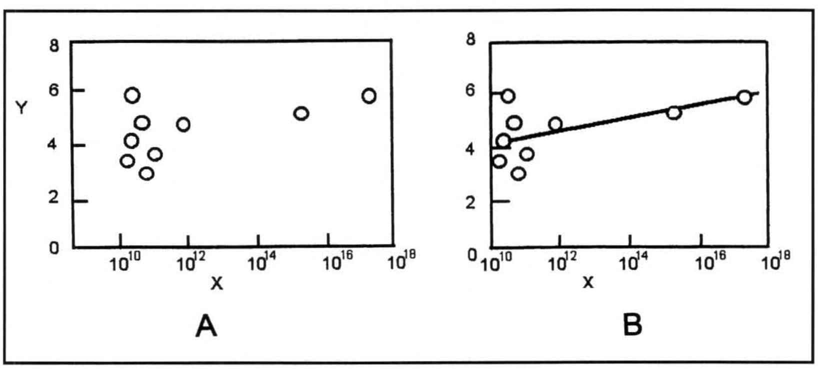

Figure 13. *Data obtained in a research experiment (A) and the plot presented by the authors (B).*

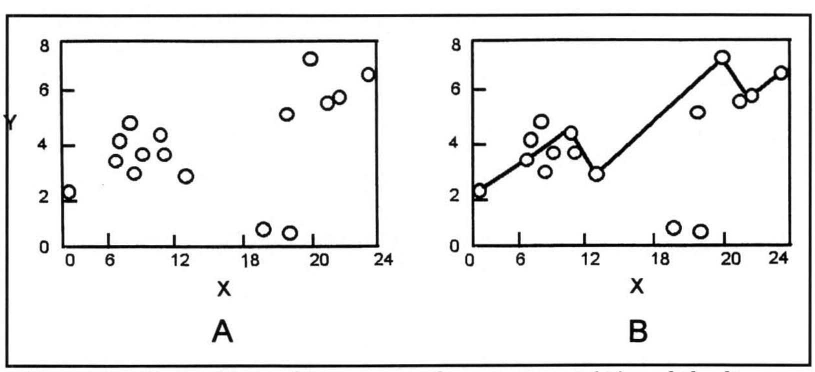

Figure 14. *Data obtained in a research experiment (A) and the line as drawn by the authors (B).*

Statistics can be used to suggest causation where none exists. The famous British prime minister Benjamin Disraeli is supposed to have said that there are three kinds of lies—lies, damn lies, and statistics. Disraeli notwithstanding, as long as statistics are calculated accurately, the result cannot represent lies. On the other hand, statistics opens up a tremendous opportunity to deceive. There is no doubt that the interpretation of statistics can be manipulated to serve the desired end.

One of the most used (and abused) statistical techniques is the least-squares fit of data. The theory is that the best fit is obtained when the sum of the squares of the vertical distances between the experimental values of Y and the line representing the relationship between X and Y is minimized. If the sum of the square of these distances approaches zero, then the fit is perfect.

The statistic used to measure this goodness of fit is known as R^2. If the calculated $R^2 = 1.0$, then the data fit perfectly. That is, we get a perfect straight line and all of the data points

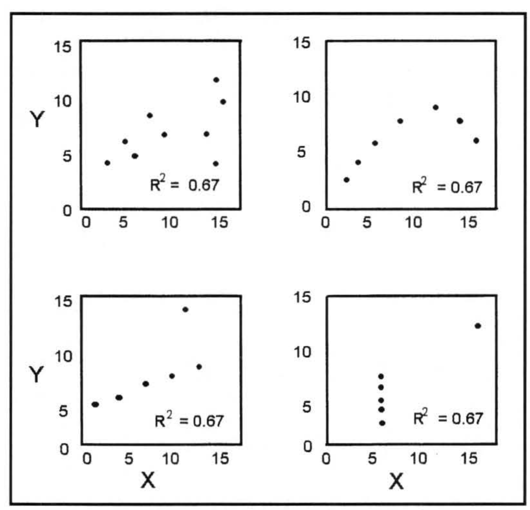

Figure 15. *Four plots with data showing identical R^2 values. (After Anscombe, F.J., "Graphs in Statistical Analysis," Am.* Statistician, ***27****, 17, 1973).*

fall exactly on the line. If $R^2 = 0$, then there is no fit whatsoever; there is no correlation between X and Y.

Shady ethics enter when R^2 is used to determine the goodness of fit without also including the plotted data, or without using common sense. Figure 15 shows how statistical correlation can be subverted.[2] The four data sets can be plotted to yield exactly the same $R^2 = 0.67$. Each data set has the same mean and is described by the same least-squares equation. And yet the data, when plotted and viewed on the plots, represent four totally different populations. Only by plotting the data would the reader understand the actual relationship between the two variables.

CONCLUSION

Depicting the truth by avoiding both lies and deceptions in engineering graphics is invariably the safest course of action for engineers. Or, as Mark Twain suggested, "Always tell the truth. That way you don't have to remember what you said."

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1. The psychology of optical illusion has been studied for over 200 years. Many of the examples used can be found in two excellents books: J.O. Robinson, *The Psychology of Visual Illusion,* Dover Publications, Mineola, NY (1992), and M. Luckiesh, *Visual Illusions,* Dover Publications, Mineola, NY (1965)
2. Anscombe, F.J., "Graphs in Statistical Analysis," *Am. Statistician,* **27**, 17 (1973); as described in Betthouex, P.M., and L.C. Brown, *Statistics for Environmental Engineers,* Lewis Publishers, Boca Raton, FL (1994) ■

Tracer Input Experiments

Continued from page 303.

student to understand and complete the theoretical lessons concerning chemical reactor design. The versatility and rapidity that comes with using a personal computer has excellent pedagogical aspects. It must be remembered, however, that it is necessary to refer constantly to the suitability of using more simple models (lower number of parameters), making some of the variables in the program constant. In this way, we avoid the problem of using models with more parameters than degrees of freedom of the system.

The time necessary for recording the responses and simulation of one curve of residence time distribution, once the preliminary steps are finished, is estimated to be between 10 and 15 minutes for a reactor of dimensions similar to the one described in this paper. This allows the student to perform a series of eight different flow rates in two hours, using the first hour to prepare and calibrate the system as well as to prepare the tracer solution. The last hour can be used to discuss different aspects with the teacher, proposal of program modifications, and other applications.

CONCLUSIONS

This class was designed for students to familiarize them with the concepts of reactor design and characterization. The reasonably good agreement between experimental and calculated values of the RTD makes them feel confident about applying engineering concepts.

The students find the experimental procedure relatively uncomplicated and possible to complete within the laboratory period. Using personal computers to study an electrochemical reactor rather than simply studying the theoretical concepts provides better comprehension of the reactor flow pattern and the model development.

It is important that the theoretical concepts be explained in class before the students attempt the laboratory exercises. Operational problems also become clear while the students are performing the experiments. For example, the importance of rapid injection of the tracer was discovered by several students who found that the response was "abnormal" in the sense that many peaks were found when non-instantaneous modification of the conductivity was achieved in the input.

Another important concept involved in this practice is the optimization method and its structure in the BASIC program. Students appreciate when someone explains how to run an optimization method such as the Simplex used in this lab session.

Students find the session interesting and enjoyable, and they relate well to the engineering principles involved. The lesson allows them to perform and validate what they have learned in class.

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