A Real World Viscosity Analysis Project

Tim Cooley
Purdue University, School of Technology

This paper presents a seemingly innocent laboratory project given to Mechanical Engineering Technology students at Purdue University in New Albany, in which several levels of traditional and nontraditional real-world challenges were presented and explored.

It was given to first-semester sophomores in our two-year Associates Degree program. The class, Fluid Power, explores all aspects of fluid power systems, beginning with a 5 week section covering the topics of pressure, energy, fluid properties, and system losses. Classroom lectures and discussions typically progress from the fundamental physics involved in each topic to its impact on the design and performance of commercial systems students are likely to recognize, such as excavating equipment or portable power units. As such, students are regularly presented with exercise questions and problems that relate the theory of the night's topic to facets they might be responsible for in industry. With this underlying emphasis in mind, the laboratory project described below was presented under the guise of a "get your feet wet" assignment the "newly hired college graduate" can quickly contribute to.

On the surface the assignment appears straightforward and traditional. Students are asked to measure a fluid's ambient viscosity using two conventional methods, then calculate an extrapolated temperature at which the fluid's viscosity reaches 50 SUS. The assignment is placed in the context of a corporate engineering project in which the results are used to support an upcoming product introduction. However, as students begin their work, it becomes apparent that each method and its results differ widely, leading to questions regarding the accuracy and reliability of both the individual instruments used as well as of the underlying measurement principles involved. The technique for extrapolation of these measurements to a final temperature also requires original thought and effort since it is presented in class but not in the required text, a situation not unlike the proprietary nature of technological advances in many companies. Finally, the assignment asks students to present and justify their results in the context of their business team, implying their conclusion is an interim step in a larger project that requires support and justification in order to minimize significant economic and personal risks. Techniques to strengthen and justify the validity of their results are then presented within the context of varying corporate cultures, from risk-taking to the most risk-averse of companies that might ultimately hire them.

By presenting this type of project to a sophomore class in an Associates Degree program, i.e. their final year before possible professional employment, the author hopes to expose students to realistic aspects of their future professional careers, along with some of the skills and strategies needed to succeed in today's corporate environment.

A. The Apparent Assignment

On the surface, this project asks students to measure the room-temperature viscosity of SAE 30 motor oil. They then determine the temperature at which it would have a viscosity of 50 SUS, the textbook lower viscosity limit for many hydraulic systems applications.

First, there are three components of data collection needed. The first two involve measurements at room temperature using a Visgage and a rotary viscometer of the author's design[1]. The third component involves collection of published information[2] from a graph of viscosity versus temperature for a range of fluids. Next the information is analyzed. Components in this section include statistical analysis of multiple samples, conversions to achieve consistent units, and determination of the viscosity/temperature constant (k) representing the oil's slope or change in viscosity with change in temperature. Finally, the determination of the new temperature at which SAE 30 motor oil should have a viscosity of 50 SUS is made, along with a short written justification of their result.

1. Data Collection

Within minutes of beginning the exercise however, students uncover complications. First, students take 5 measurements from each of three Visgages, giving a total of 15 samples. All instruments are in excellent condition in their original cases and accompanied by the original instructions. But while Visgages are popular in the field due to their simplicity and portability, and display units of SUS (the units presented in the exercise objective), students quickly discover that measured results differ widely from one instrument to the next, with no apparent physical explanation. Each instrument has good repeatability, with a mean variability of approximately 5%, yet instrument-to-instrument variability can exceed 30% depending on the instrument used.

Next, students measure viscosity with a rotary viscometer designed by the author[1]. This viscometer is introduced and its operation explained as if it were a "proprietary" company design with capabilities superior to other commercially available models (such as the Visgage). It is purely mechanical in design so students can visualize and measure not only the geometry of a rotary viscometer system, but also the physics of the torque reaction and its measurement. The viscometer uses the US units of $lb_f\ s/ft^2$ and has good accuracy compared to published data [1], with only a slight dependence on rotation speed. Students take a single measurement at each of its speeds, for a total of 3 samples.

The third component of data collection involves reading a graph of published information on the change of viscosity with temperature. This graph serves the direct purpose of providing standard data points for the determination of the viscosity/temperature constant (k). It is also used at the end of the exercise, during the class discussion of methods to reduce personal and professional risk in decision making, to remind students of the potential value of including previously published information in defense of their own results.

2. Analysis

After all data collection is completed, the analysis section commences with calculation of viscosity in the case of the rotary viscometer, units conversions, determination of the viscosity/temperature constant (k), and finally calculation of the temperature (T2) at which the oil's viscosity would equal 50 SUS.

For the first calculation, viscosity using the rotary viscometer, the equation is presented both in class presentation and in a handout of the geometric basis for the viscometer itself. This presentation also serves as the stage for the exercise supposition that the instrument is "proprietary" from the company's standpoint when compared to the Visgages. The resulting equation requires input of only the amount of counterweight (in grams), its steady-state angle (in degrees), and the speed of the turntable (in rpm).

Unit conversions are accomplished with the assistance of Esposito[3 p44]. The task of conversion is required several times during the exercise since Visgage readings and the viscosity at T2 are in SUS while the rotary viscometer and the published data graph use units of lb_f s/ft^2.

Calculation of the viscosity/temperature constant (k) is similar in concept to the standard viscosity index (VI) except it does not require a comparison with other fluids. Instead this analysis is presented in class as an exercise in the recognition of viscosity's inherent logarithmic behavior, with the resulting equation based solely on the documented behavior[2] of the intended fluid. The specific value students are seeking for the constant (k) results from the equation;

$$k = [\log(\mu_1) - \log(\mu_2)] / [T_1 - T_2]$$

using graphed points for SAE 30 in the first and second values of temperature (T) and viscosity (μ). Algebraic manipulation and substitution are then used (in conjunction with the student's data) to determine the final temperature (T2) at which SAE 30 motor oil viscosity should equal 50 SUS. This method of viscosity analysis is not discussed in the required text.

It is important to note at this point, however, that each of the analytical component of the above assignment had been given previously in homework exercises. In essence then, this exercise is merely a compilation of previous work, packaged in a form resembling a possible assignment for a new employee.

3. Conclusion & Justification

With the above components completed, students are ultimately asked to present, in corporate memo format, the final temperature (T2) at which the new product soon to be introduced will safely operate. They are reminded of the project team and corporate contexts framing the exercise, encouraged to ask any final lingering questions, and dismissed from class to complete the assignment. Students are expected to include a paragraph in which they provide a written justification in support of their answer (and therefore the product introduction).

B. The Real Assignment

As students begin working on this assignment three levels of challenge soon appear. At the most concrete level come issues regarding the data itself. At a more abstract level are issues regarding analytical techniques and their application. Finally, once the second temperature (T2) is determined, the most abstract level of real-world learning is exposed as students are asked to defend their work, i.e. substantiate their findings so subsequent financial decisions can be trusted and their professional conduct can be established. It is within this framework of real-world challenges that the concept of the corporate culture of risk-taking, and its influence on professional success it introduced and explored.

Level One – Data

Several data-related questions arise early in the students' work. First there is the question of how to deal with differing results from seemingly identical instruments. None of the Visgages is damaged or physically different from the others and their individual results are very consistent, yet the indicated viscosity values for the same sample of oil differ by as much as 30% from instrument to instrument. Students are essentially faced with the question of which instruments to believe, and then how to treat the entire data set to resolve this question. Second, students were instructed to take 5 separate measurements from each of 3 Visgages, yet only one measurement for each of 3 speeds from a single rotary viscometer. This discrepancy inevitably leads to questions concerning the impact of the individual data on the result. Or in the students' words, do 15 Visgage measurements really count five times more than 3 rotary viscometer measurements, especially if some of the Visgages are "weird". This question is intentionally compounded by the author during the rotary viscometer's initial discussion, where it is pointed out that this "company" instrument has been shown to be highly accurate and yet the students have never seen or used it before. This preferential-treatment challenge is similar to the situation in which an employer has its own proprietary equipment and places increased emphasis on its use and results, above those of more familiar equipment the employee may have been exposed to previously. Third, after calculation of all viscosities and conversion to consistent units, students observe that all Visgage viscosity values, encompassing the majority of their data, are significantly below those of both the rotary viscometer as well as the published values from the graph.

Taken together, these complexities highlight the most fundamental real-world type of challenge a student will experience in industry; when faced with multiple sources of potentially conflicting information, which is to be believed, and to what extent can it be used in subsequent analysis? For students continuing towards their Bachelor's degree, these questions can be at least partially addressed in a future statistics class. For purposes of this class, however, the author first assures students that mathematics does have techniques to objectively address if not fully resolve this quandary, before moving on to the fact that these techniques still don't address the more difficult and significant level-three problem yet to be discussed.

Level Two – Analytical Technique

Most people make the (hopefully correct) assumption that colleges and universities impart knowledge to their paying customers. An aspect often overlooked, however, is that this knowledge must be effectively applied if it is to be useful. Two subtleties appear in this exercise that serve to emphasize this distinction to students. First, while the task of units conversion is common in most engineering technology classes, in this exercise students discover that conversion of viscosity units in one direction is significantly more difficult than it is in the other direction. By design, both the first instruments used as well as the final temperature desired are presented in terms of SUS units. Yet going in the US (lb_f s/ft^2) to SUS (t) direction, as students would normally assume by the design of the exercise, is actually relatively difficult. Recognition that conversion in the opposite direction (SUS → cS → cP → US) is ultimately much simpler involves recognition that, while there are many paths to an end, taking the time to evaluate those paths prior to engaging the task can significantly impact the amount of effort expended. This awareness of the process of solution speaks directly to students' ongoing educational need to correctly identify, analyze and solve technical problems. It demonstrates the benefits of analyzing the sequence or process involved, i.e. how best to get to the endpoint, not just the mechanics of the solution step.

Second, explanation and derivation of the viscosity constant (k) is based on work presented in class by the professor, and is not available in the book. It is placed in the context of the exercise to resemble project instructions given in a project team meeting immediately prior to its use. This kind of presentation is meant to reinforce recognition that business-related technical information is often given in a meeting format that is not always duplicated in writing elsewhere. Although students had some familiarity with this constant (k) through a previous homework assignment, if any remaining questions still existed regarding its derivation or use, they should be prepared to resolve them during the presentation, when this last opportunity presented itself.

Level Three – Corporate Culture

The third level of challenge is perhaps the most difficult for the typical student to grasp. Their degree of perception is primarily dependent on their maturity and prior personal experience in a corporate environment. This level of challenge ultimately explores the influence of the risk-taking culture they hire into, even with a project as apparently simple as calculating a temperature. By presenting the exercise as a small project nested within a larger, more important corporate project such as a product introduction, students are introduced to the fact that there can be more-significant repercussions for their decisions and results than are apparent from the project itself. Therefore, it is very important that they justify their decisions and reinforce their results. In the context of this exercise this implication is examined through the question of how to support an unexpected result upon which a larger, more expensive financial decision has already been made.

As part of the initial information they are given, students are supplied with the most objective and substantial information available; published performance of the same fluid they are testing. By design, however, this fact is not pointed out until after their work is submitted. Instead, the assignment merely states that their work will have significant business and professional implications that need to be addressed. Therefore they need to justify and substantiate their result in an accompanying paragraph. There is also the verbally stated expectation that the results are already known to be in the range of 230 degrees Fahrenheit, and that deviations from this range will negatively impact the product introduction. This fact (230 degrees F) comes directly from the published graph they are given, although this is not explicitly divulged until after the exercise is submitted. By the time the assignment is submitted students have realized that their actual result indicates a somewhat lower final temperature (T2) and they find themselves in a situation of having to document their result against this conflicting expectation (and its consequences).

The following trajectory is used in the summary discussion to present and explore this ultimate real-world challenge. First, it was actually expected that students would calculate a lower final temperature than 230 degrees F, due primarily to the influence of the Visgage data and the lack of explicit prior instructions on techniques to address potential instrument inaccuracies. Second, the objective data were always available to them that substantiated the desired result of 230 degrees F, and it should have been included in their report even if their own results differed. This contrast serves to demonstrate the benefits of their professional diligence in including all relevant information even if it does not directly support their specific result. Third, given that their result had larger financial implications, they would likely be asked to "revisit" their result even after submission. In other words, future employees should be aware that there will most likely be some managerial pressure to modify their result so it conforms to the previously expected answer of 230 degrees F. Next, the way the exercise was given to them, students were in fact asked only to reinforce a previous result. But by arriving at a different result and having to justify it, each future employee was being exposed to an aspect of corporate culture called risk-taking whereby they are actually being examined for their ability to handle deviation from an expected norm. The company may have been more interested in the employee's reaction to this unexpected finding, in other words their response to the risk inherent in nonconformance, than to the finding itself. Finally, with each company having its own unique attitudes and tolerance for risk-taking behavior, it is important that students recognize not only the company's culture but also their own attitudes and reactions to its influence and its potential impact on their professional conduct.

Even with this trajectory of discussion, however, some students have difficulty grasping this most abstract of real-world challenges. As a result, it is not usually explored in depth. Instead, level-three aspects are summarized by stating that results should always be reinforced, especially if they deviate from expected values, since they virtually always have additional implications downstream of the assigned project itself. Depending on the level of maturity and experience of the class as a whole, additional elaboration may be undertaken as discussed below.

C. Strategies for Successful Project Completion

Experience has shown that students have little if any recognition of the true depth of this exercise when it is first assigned, even with point-by-point discussion by the author. In order to return this exercise to its proper perspective as a classroom assignment then, the author follows the above level-by-level discussion with these summarizing points:

1. Methodology is important, not only in the data collection phase, but also in the analysis phase. The ability to examine the process of solution, as well as the individual steps involved can have a big impact on the amount of effort expended to complete it. And this ability isn't lost on their employer.

2. Like most real-world projects, this exercise involved very little original work. Instead it required building a larger, more significant result from several known quantities that had already been examined prior to this exercise. As stated above, all the analytical steps had been previously assigned as homework, and none should have presented any unique challenge or difficulty by this point in the semester.

3. Corroborating information is valuable and should always be included in the work submitted, especially when results deviate from expected norms. If nothing else, inclusion of published values demonstrates that the employee is at least cognizant of the big picture and how his or her individual results fit within it.

4. Even seemingly simple exercises can have larger consequences, both economic and professional in nature. Recognition of this fact is often viewed by potential employers as a significant indicator of an employee's future potential in the company.

5. The influence of corporate culture on risk-taking behavior can have a large impact on an employee's work, and recognition of this influence can be important to a person's professional success.

D. Student results & refinements

Of course, after an assignment such as this there is the inevitable question; "so, how did they do?" with the likewise predictable answer "that depends". The Associates Degree program at New Albany typically contains a large percentage of nontraditional students with several years of corporate experience. These students can often identify with many of the level-two and level-three aspects of this exercise and are asked to share their experiences with the class. There are also more traditional students, approximately 19 years of age, with virtually no professional experience. These students are also likely to have a very limited perception of the higher levels of difficulty this exercise presents. They benefit more from discussion of the level-one issues, especially when other students can share similar real-world experiences they have had.

Finally, as the real-world issues involved in this exercise become visible, some students are tempted to stop working and accept a lower lab grade, regardless of the implications. To minimize this problem the author segments the assignment to insure consistent student progress throughout the exercise. By specifying interim completion dates and allowing class time to discuss progress and difficulties, students have better success identifying and addressing these issues and are better able to extend themselves into the higher-level issues presented.

Bibliography

(1) Cooley, T., A "New" Viscosity Instrument and Exercise, 2003, Proceedings of the 2003 ASEE National Conference.

(2) Mott, R. L., Applied Fluid Mechanics, 5th Ed., 2000, Prentice Hall, page 559.

(3) Esposito, A., Fluid Power with Applications, 6th Ed., 2003, Prentice Hall.

Biography

Timothy R. Cooley is an Assistant Professor at Purdue University in New Albany, Indiana. Professor Cooley received his Bachelors and Masters Degrees in mechanical engineering from the University of Oklahoma in 1981 and 1984 respectively.