2006-346: HOW TO RESCUE A POORLY OPERATING EXPERIMENT IN AN ENGINEERING TECHNOLOGY LAB AND TURN IT INTO A "REAL-WORLD" LEARNING LESSON

Francis Di Bella, Northeastern University

Michael Koplow, Northeastern University

Mr.Koplow is an ADjunct instructor at Northeastern University and has instructed Thermodynamics for the mechanical engineering technology unit. He has over 30 years of experience in energy research and also operates a consulting company, Emdot Engineering.

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How to Rescue a Poorly Operating Experiment in Engineering Technology and Change it into a "Real-World" Engineering Technology Learning Lesson

Francis A. Di Bella, PE Director of School of Engineering Technology
Michael Koplow, Adjunct Instructor Thermodynamics
Northeastern University, Boston, MA

ABSTRACT

A planned experiment that goes awry can never be completely avoided. Even the best planned lab experiment in an engineering technology course will suffer a somewhat embarrassing failure in the middle of the experiment, with a lab team of engineering technology students looking on, dispirited and possibly embarrassed for the seemingly helpless instructor. But this is the precise moment and opportunity when the engineering technology lesson can be enlivened and saved from failure and when the instructor can provide the greater lesson to the student which, in the words of the non-engineer Winston Churchill is: never give up, never give up, never give up! This paper explores the strategy of turning a lab experiment failure into an engineering technology learning lesson that will not soon be forgotten by the engineering technology student.

Background and Introduction

Any Instructor or Teaching Assistant has likely had the experience of starting an engineering laboratory experiment only to find that the experiment does not work completely. This can be true even when the experiment "…worked a minute ago" during the trial test; before the students arrived at the experiment. In the instances where the experiment is conducted by only a Teaching Assistant (TA), the failure may not be brought to the classroom instructor's attention and if it is, it is usually only after the class has struggled with the experiment and has given up on operating it during the time allotted for the lab and has left the lab for the next class.

This unfortunate but, in the opinion of this author, inevitable incident is particularly grievice for engineering technology students whose classroom work and attentions are heightened by the laboratory experience. The need for the lab to compliment the classroom work compels the Instructor to reschedule the lab. But this rescheduling is often difficult if possible at all due to the extensive course schedule that is being maintained by the engineering technology student.

The old adage about "…learning more from your mistakes" has an even more true (and longer) corollary that may be stated as: "Every failure is rife with opportunity to learn about the causes of the failure and the logical and rational diagnostic procedures that are employed to determine this cause typically results in the investigator in learning at an accelerated rate". This paper presents the argument that the only satisfactory alternative is to make use of the failure as an opportunity to teach the engineering technology student.

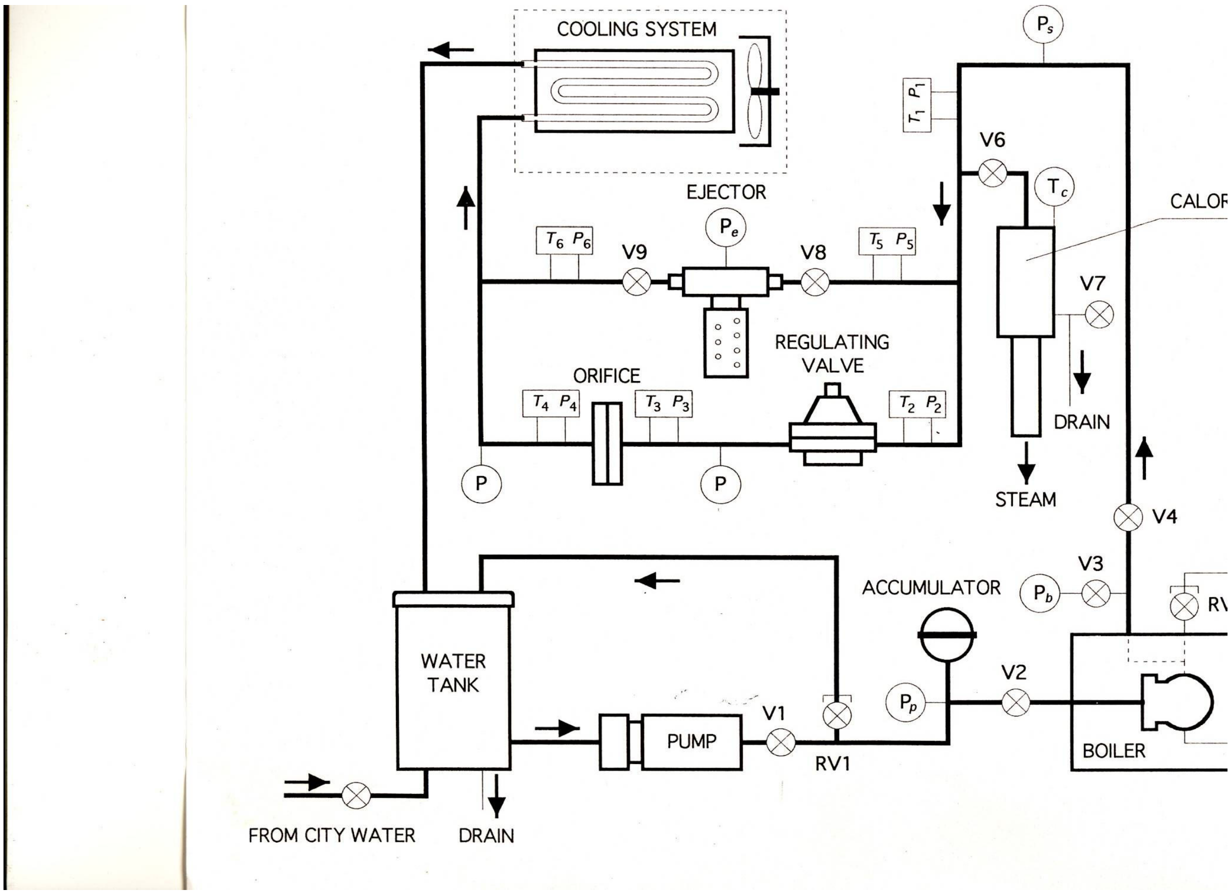
Turning Lemons into Lemonade

This paper was conceived after a recent thermodynamics experiment started badly but seemed to transform itself into a significant learning exercise for the students. The very net positive experience as expressed by the students provided the a revelation to the instructor that not only do "…you learn more from your mistakes" but also, perhaps these "mistakes" should be scheduled into the actual experiment to promote a more interesting experiment for the students; one that they can be more involved in than otherwise is the case for typical experiments.

Consider the following incident.

The student's first class in thermodynamics has a scheduled lab experiment to emphasize the measurement of steam pressure and temperature, the vapor pressure-temperature relationship, and the measurement of steam quality using a steam throttling calorimeter. The piping and instrumentation diagram for the experimental apparatus is shown in Figure 1. The piping includes several parallel loops, valves, flow meters, water pump, condenser/fan assembly, a 3,000 watt electric steam boiler, power meters, thermocouple and pressure instruments and transducers. The purpose of the lab experiment is straight forward: to boil water at different pressures and record the pressure and temperature. Check the recorded temperature and pressure against the steam charts. The system also includes a throttling calorimeter that the student will use to measure the enthalpy of the steam as it exits the boiler.

The instructor implores the students that they must first get thoroughly familiar with the test apparatus by tracing the piping and carefully redrawing the piping network. The students comply but are just a little more than going through the motions to get the drawing completed as quickly as possible. After all, the system is operating properly, isn't it? The piping must be correct, the steam is being generated and carried through the piping to all of the correct destinations: valves, flow meters, condenser/fan assembly, etc.



Once everyone has "thoroughly" understood the plumbing, the system is started by turning on the 3,000 watt steam generator to be followed by a period of waiting for sufficient steam to be generated to heat all of the piping and establish a steady-state flow rate through the flow meters. But this is when something went wrong and where, by everyone's account, it got more interesting.

The steam generator reached a temperature of 150 F and power to the steam generator shuts off unexpectedly. A check of the fuses is made and confirms that the fuses are operational. A check of the pressure is made and confirms that indeed the steam boiler pressure is still at 0 psig. The system is started up again with the declaration by the Instructor that the system shut down is a fluke.

An identical start and stop is experience several more times after waiting 5 to 10 minutes for the mysterious 150 F maximum temperature to be reached.

The student's impatience is growing and is apparent by the rustling of papers and scraping of chairs.

So…students, there seems to be a problem with the apparatus. Anybody have any suggestions? No…well let's look at this logically?

Is the temperature at which it is shutting always 150 F? How do we know that the temperature measurement is correct?

Maybe the temperature instrument is not in the live steam line from the boiler? Did everyone/anyone trace these lines and not just redraw the piping and instrumentation diagram that came with the experiment write up…which by the way has a date of what exactly and drawn by whom?

Are valves 1, 2 and 3 opened or closed? What should they be based on the piping diagram? Who checked the valve positions before we started?

Maybe the generator is actually generating steam. Is there really steam being generated but the pressure and temperature gauges are wrong and/or not working? Should we have calibrated the instruments first to be sure they are working?

Carefully touch the lines beneath the insulation. Are they warm? Yes. Too hot to touch? No.

We've been waiting over 5 minutes for this boiler to heat up. How long does it take to heat the standing pool of water in the steam boiler? To answer this you need to know how much water is held by the steam boiler. If the steam boiler label doesn't indicate the volume of water, can we determine how much water it can hold by the outside dimensions of the boiler? Remember the equation for this heat transfer from the class lecture?

How much heat would be needed to heat up all of this steel piping?

Maybe we haven't waited long enough for the boiler to actually heat up? Based on the amount of water in the tank and the rating of the boiler, how long does it take to heat this water to boiling temperatures? According to the basic "closed" mass thermodynamic energy balance it should take about 20 minutes. How long for the boiler to heat water to about 150 F from a cold start? Only about 12 minutes, which is about the time it took to heat up the first time we tried the test. Everyone: check your Journal entries for the time that you recorded for the length of the first experiment, at least up until the system shutdown. What's wrong? Didn't anyone record the test time of the first test? What do you think the Journals are for?

Is there electric power going to the steam boiler? What were the readings of the Watt meter on the control panel? Who recorded the reading of the watt meter during the last test in his/her journal? Anyone? No one! Why not?

Does this electric steam boiler have an automatic safety pressure or temperature switch to protect against over pressure or over heating? Let's take a look at the wiring diagram for the control panel? No. Then let's take a look at the wiring of the steam generator to find if it has a built-in temperature switch. Not sure without partially disassembling the boiler. Wait, does anyone have a laptop with internet capability[1] that can be used to look up the manufacturer of the steam generator and get the steam boiler specifications or perhaps a local manufacture's rep?

Well according to the manufacturer there should be a variable temperature control knob somewhere on the front of the steam boiler. But there's no temperature control knob …wait a moment, there it is behind this heavily insulated pipe which blocks its view from the operator. Who designed this "simple" piping system anyway. Isn't the piping system supposed to be perfect? Hasn't it been checked by a responsible engineer before the students entered the lab?

At last the answer to the mystery: the temperature control knob was set on a low temperature setting of 150 F. Why?… Because the control was confused with a power control dial! Rather than wanting to set the steam boiler at a safe 1500 watts, the control was inadvertently actually limiting the temperature to 150 F.

This entire exchange consumed most of the two hour lab as calculations were made and double checked by the students, water and steam properties were looked-up from the textbook, web sites searched, piping and instrumentation checked again and again (but this time with a purpose and a mission to accomplish), and the system restarted several times.

The students were engaged with the Instructor throughout the exercise, participating in all of the calculations and with the selection of the next rational check of what to do to diagnose the system.

In short, the thermodynamic experiment was saved and even more vital to the education of the student. What is the evidence for this "…more vital education of the student"?

Steam Boiler Redux

The answer to the question and thus a validation of the pedagogy expressed in this paper is offered by examining the initiative and interest of several students in the very next thermodynamics assignment that is part of the same thermodynamics lab course.

As part of the thermodynamic course, the students are expected to select a thermodynamic problem for which the system can built from scratch, instrumented and tested. The problem theme can be chosen from a number of sources. The student is encouraged to, at the very least, go to any end-of-the-chapter problems in the thermodynamics textbook and select a problem that interests them enough to want to actually construct the system and then test it. The Instructor also makes some suggestions. Several of the students immediately chose to build a small steam boiler system, and in this instance one that can be more properly identified as a water heat pipe. The heat pipe consists of an evaporator boiler section and a condensing section. The

[1] This last inquiry forces a look of astonishment from more than one student who remind the Instructor that this is the "Flat World" generation of engineering students in the 21st century and, oh by the way, prof. ... look you don't need an internet cable anymore!

evaporator section is actually a small diameter cylindrical vessel approximately 3 inches in diameter and 14 inches long. The condensing section was initially constructed of ¼ inch diameter, bare tubing which was later replaced with a section of finned tube convector heat exchanger. Figure 2 illustrates a preliminary sketch of the water heat pipe concept that was to be fabricated and built by the students. Figure 3 shows the two students and the instructor (and co-author) in the process of building this water heat pipe.

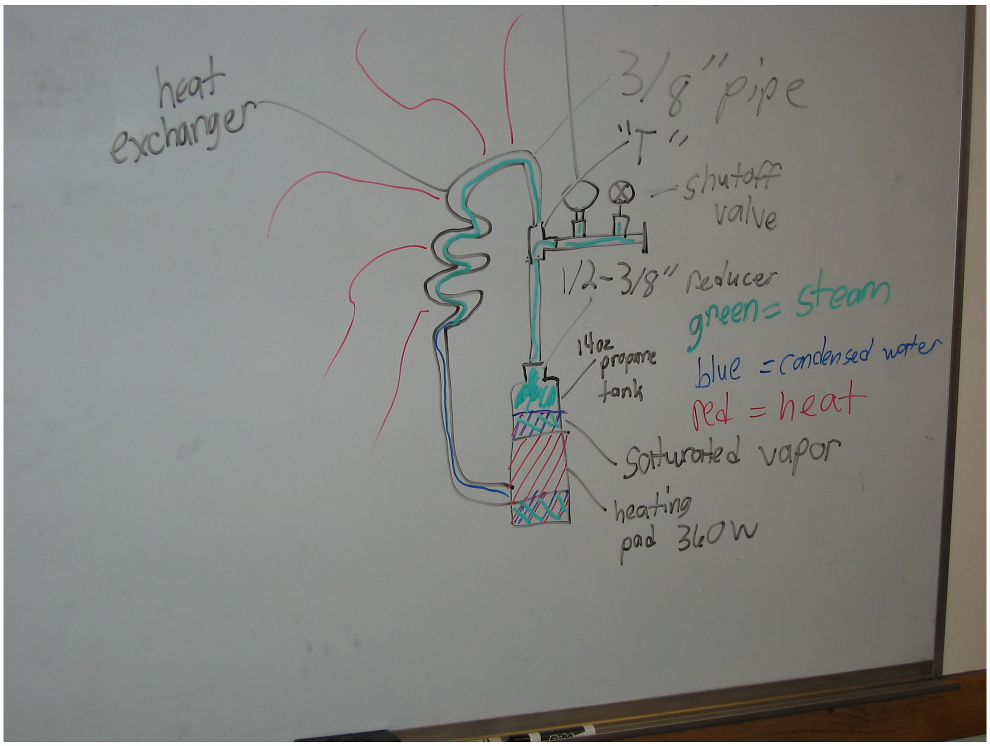


Figure 2. Preliminary sketch of the water heat pipe design concept.

Figure 3. The water heat pipe assembly in progress.

The students spent one lab period designing the heat pipe system and preparing a bill of materials. The materials were ordered and delivered before the next week's lab session. The students then spent the next two lab sessions constructing, testing and redesigning and modifying the heat pipe. The final design of the heat pipe system, with the modified extended tube section is shown in figure 4. The electric power cord is connected to a heating pad that serves as the heat source for the heat pipe evaporator and the extended surface (with a manifold suitable for a fan, not shown) serves as the condenser section for the heat pipe system.

Assessment

Clearly this methodology would be moot if it did not contribute to the education of the students and, somewhat to a lesser extent, if the students did not care to fully participate in the pedagogy. The later is important because a student's education is effected by whether the student is involved, committed, excited, and otherwise mentally present during the educational exercise. The excellent results of this experiment, as witnessed by the instructors, was convincing enough to have this methodology be applied again, whether intentionally or unintentionally but only with the correct Instructor at the helm. The Instructor must be prepared to ask the questions as shown in this vignette and not be too concerned that an unplanned "experiment" may reveal more about the instructor than is comfortable.

As for the students, the two students involved in the heat pipe design and assembly wrote in the course evaluation that there should be more hands-on assembly such as performed in this lab; this coming from two students who have seen other labs in other courses where the experiments were more of the typical, pre-assembled, "just-turn-the-power-on" type of experiment.

Was there a lesson learned? Notice in figure 4 that all of the gauges are readily visible for the operator as designed by the students. In other words: Yes, lesson learned!

Conclusion

The case study used to demonstrate the application of "…learning from your mistakes" in this paper has been illustrated using a thermodynamics example. Certainly, any laboratory experiment can be "saved" and even improved upon by the instructor who may even help the educational process along by intentionally compromising (perhaps "sabotaging" the experiment is too harsh a description) the system. The experiment can then be turned into a project that either improves the existing apparatus or, as discussed in this paper, encourages the students to devise their own design that can be built and tested. In the view of the authors there is not a better way to train engineering and engineering technology students to expect to conduct "hands-on" application of their diverse class room instruction.

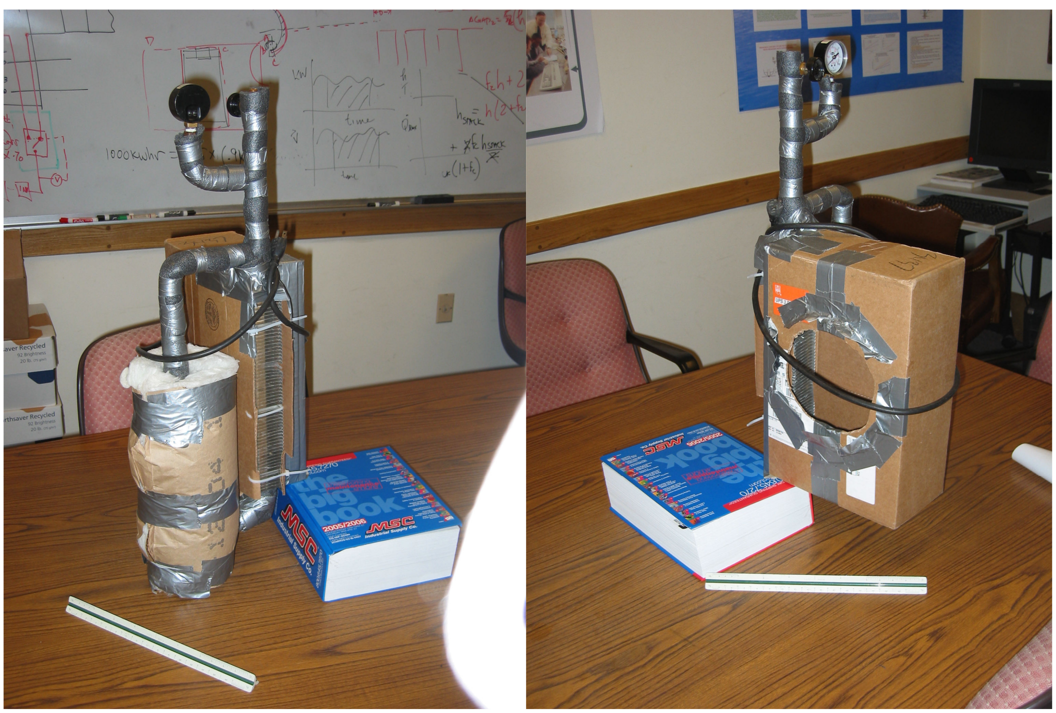


Figure 4 a and b. Final assembly of the Steam Boiler Heat Pipe as used in the final lab test.