# AC 2009-308: INCORPORATING LEARNING STYLES INTO CONTINUING ENGINEERING EDUCATION: A PROCESS HEATER CASE STUDY

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# Incorporating Learning Styles into Continuing Engineering Education: A Process Heater Case Study


## Abstract

Lifelong learning is critical to an engineer's success over the course of their career. Some topics are too specialized to be covered in the typical engineering program and need to be learned after graduation. One specific example considered here is process heaters used in the hydrocarbon and chemical processing industries (HPI/CPI) to heat hydrocarbon fluids that are being converted into fuels like gasoline and chemicals like ethylene. The John Zink Institute has been teaching a course on process burners used in those heaters for many years. However, until fairly recently, relatively little consideration was given to adjusting the instructional methods to accommodate the various learning styles of the students. This paper describes how multiple techniques addressing different learning styles are used to help explain a somewhat complicated, but critically important concept in that course, for properly operating process heaters.


## Introduction

Continuing professional education is critical for graduate engineers because of rapid changes in technology.[1-4] This education may take a variety of forms ranging from 30 minute webinars to advanced graduate degree programs. This paper focuses on technology-specific short courses that generally last one to five days, eight hours per day. Here, the short course is on burners used in process heaters (see Figure 1). It is important to note that most undergraduate chemical and mechanical engineering programs have very little if any content on combustion. Therefore, most graduates who work with fired heater equipment learn theory and application in their field after graduation, through a combination of on-the-job training, magazines, journals, books, and courses. This paper focuses on a course that uses a variety of techniques to teach heater control.


Figure 1. Photo of a typical short course class.

The John Zink Institute has delivered training on process burners and heaters for many years. Up until about 10 years ago, the predominant method of instruction was lecture using 35 mm slides. Students received a manual with black and white copies of the slides and a textbook entitled *Furnace Operations* written by the company's Technical Director.[5] There was relatively little interaction, other than questions, between the instructor and the students. No instructive simulation models were available at that time. One of the more difficult concepts to understand in the course is how to set the excess $O_2$ and the draft level in a heater, both of which are critical for proper performance. Multiple techniques for different learning styles have been developed over the past five years to teach this concept in the course.

**Process Heaters**

Process heaters (see Figure 2) are used in the chemical and refining industries to heat hydrocarbon fluids flowing through tubes inside the radiant and convection sections. Most of these heaters are natural draft, which means no fans or blowers are used to supply the combustion air to the burners and remove the combustion products from the heaters. Heater draft refers to the negative pressure that develops when hot gases rise inside the heater. Draft pulls in the air needed for combustion and pushes out the products of combustion such as $CO_2$, $H_2O$, $O_2$ and $N_2$. Excess $O_2$ refers to the amount of oxygen in those products of combustion. Ideally, this excess $O_2$ should come from the air being pulled through the burners, although some also comes from air leaking into the heater, which is called *tramp air*.

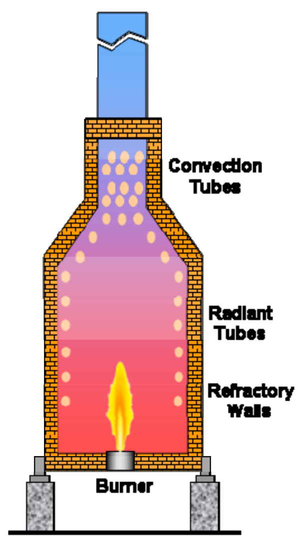



Figure 2. Schematic of a typical process heater.

It is very important that the draft and excess $O_2$ levels are closely controlled to ensure safe operations, maximize thermal efficiency and productivity, and minimize pollution emissions. Figure 3 shows how thermal efficiency varies with excess air based on theoretical equilibrium calculations for "air" consisting of 21% $O_2$ and 79% $N_2$, on a volume basis, reacting with methane. The exhaust products are assumed to be at 2000°F. Notice that the thermal efficiency decreases when excess air increases above 0%. This decrease occurs because of the added heat load from the extra $O_2$ and $N_2$ in the air that absorbs heat which is carried out with the flue gases. Also notice that the thermal efficiency decreases when the "excess" is below 0%. This decrease occurs because there is insufficient oxygen to completely combust all of the fuel, which means that not all of the chemical energy is converted into thermal energy. Insufficient air is also potentially unsafe because the unburned fuel could be ignited somewhere else inside of the heater. For example if tramp air is leaking into the convection section, the unburned fuel could mix with this air, which could lead to "afterburning". It is not the point of this article to discuss all potential safety problems and it is the operator's responsibility to assure safe operation. However, it is important that process heaters operate with sufficient oxygen to ensure complete combustion in a controlled manner.

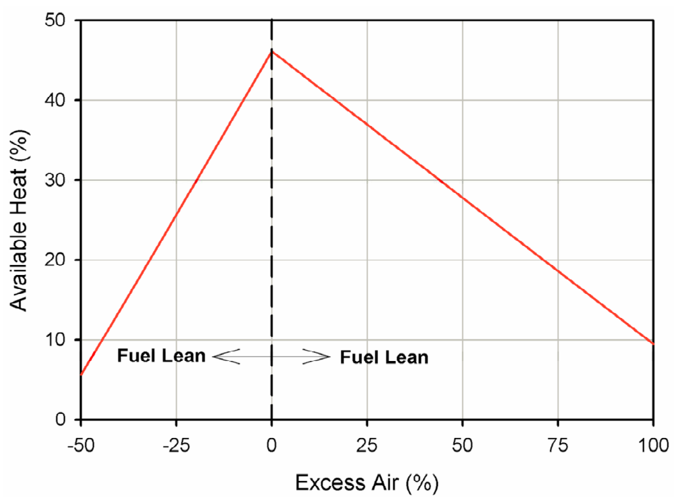



Figure 3. Available heat vs. excess $O_2$ for methane combusted with ambient air (2000°F flue gas temperature).

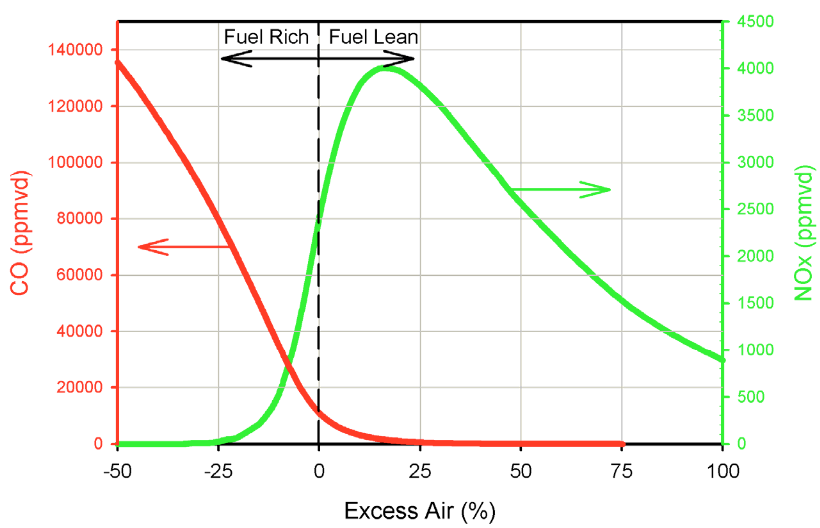



Figure 4. NOx and CO vs. excess $O_2$ for methane combusted with ambient air.

The two most common pollutants regulated in process heaters are carbon monoxide (CO) and nitrogen oxides (NOx).[6] These pollutants are sensitive to the amount of excess $O_2$. Figure 4 shows that with increasing excess air levels above 0%, the CO decreases and NOx increases. Ideally, the goal is to minimize both pollutants, which can be challenging since each reacts oppositely to excess air levels. Ultra low NOx burners use a variety of strategies to minimize both pollutants.[7] High levels of CO indicate incomplete combustion and improper burner operation. High NOx emissions are a problem if they exceed permitted limits. Therefore, heater $O_2$ levels are typically controlled to levels as low as possible, without forming high levels of CO, to maximize thermal efficiency and minimize NOx emissions. Often a manually-operated heater will be run with slightly more $O_2$ than is optimum to account for any variations in ambient air (e.g., temperature and humidity), fuel (e.g., temperature and composition), and process operating conditions (e.g., feed flow rate).

Figure 5 shows burners firing across the floor from both sides of a process heater. The figure on the left shows the heater before the $O_2$ and draft were properly adjusted. Notice how ill-defined the flames are and how relatively cold the heater is because of incomplete combustion. The figure on the right shows the flames after the $O_2$ and draft have been properly adjusted. The fuel composition and firing rates are essentially the same in both cases. The flames in the right photo are now well-defined and the heater is hotter which typically means more throughput of hydrocarbon fluids. These heater adjustments are the responsibility of the plant operators and underscore the need for proper training and experience. The photos in Figure 5 show how proper adjustments improve flame quality. Training gives operators a clear physical understanding as to why these certain adjustments make the desired improvements. A better understanding of the why can help operators and engineers maintain peak performance over a broader range of operating conditions and allow them to better troubleshoot problems and plan for maintenance and equipment upgrades.

(a)

(b)

Figure 5. (a) Before and (b) after adjusting the $O_2$ and draft in a process heater.

An operator can control the heater draft and excess $O_2$ by adjusting the damper on the heater exhaust stack, referred to as the stack damper, and on each burner, referred to as the burner damper. Although both the stack and burner dampers impact the draft and $O_2$, the stack damper is primarily used to control the heater draft, while the burner dampers are primarily used to control the excess $O_2$ in the heater.

To accommodate a variety of learning styles for teaching these important concepts, a combination of techniques has been developed to teach them to both engineers and operators working in chemical plants and refineries. These techniques include written descriptions, flowcharts, graphs, tables, everyday examples of similar phenomena, examples from actual process heaters, and a heater simulator. The techniques are categorized next according to learning style.

**Learning Styles**

Most education scholars agree that learners have an identifiable and preferred learning style, although they disagree about how to define or explain those styles.[8] Some concentrate on the cognitive aspects of learning, some on affective approaches to learning, some on the environmental aspects of learning, and still others on the perceptual modality which is the approach considered here. There are multiple elements that compose the perceptual modality: print, aural, interactive, visual, haptic, kinesthetic, and olfactory. A print-oriented learner learns best through reading and writing. An aurally-oriented person prefers to learn by listening. A learner who likes to talk and discuss ideas would be considered an interactive learner. A visually-oriented learner likes to see pictures, slides, graphs, etc. Haptic learners are “hands on” and prefer to learn through touching and feeling. Kinesthetic learners prefer to move around while learning. Olfactory learners prefer to learn through smelling and tasting.

Some of these preferences are not always relevant in a particular learning situation. For example, haptic and olfactory are only applicable in those circumstances where the object of learning can be touched, tasted, and smelled. Kinesthetic may be limited in the typical classroom as it may be disruptive for learners to be walking around during class which would be distracting to non-kinesthetic learners. However, it may be possible for kinesthetic learners to use their hands or feet in ways that would not be as distracting.

The elements that are specifically considered here are print, aural, interactive, and visual. Each is discussed next. Haptic teaching methods are possible as test heaters equipped with burner and stack dampers are available. However, all demonstrations in test heaters are conducted strictly by personnel certified to run the heaters, to prevent unsafe conditions from being created.

Print Teaching Methods

Students are provided with a copy of the *John Zink Combustion Handbook*[9] which is a textbook in full color that provides a written description of excess $O_2$ and draft. Many of the course instructors have contributed materials to the book, which is primarily used as a reference for the students. Each student also receives a training manual containing the presentation slides in color. Plenty of space is provided for learners to make notes in the manual. Some of the slides also contain blanks designed to be filled in by the students to help encourage them to stay engaged and keep up with the instructor.

Table 1 is a print device designed to show learners how opening or closing the burner or stack damper impacts the excess $O_2$ and draft. The color, direction, and size of the arrow indicate how the variables are relatively affected. The upward-pointing green arrow indicates a variable increase, while the downward-pointing red arrow indicates a variable decrease. The larger the arrow, the more it is impacted by the change. For example, opening the burner damper causes the excess $O_2$ to increase significantly and the draft to decrease slightly.

Table 1. Effects of burner and stack damper positions on $O_2$ and draft.

| Device | Position | O2 | Draft |
|---|---|---|---|
| burner damper | opening | ↑ | ↓ |
| | closing | ↓ | ↑ |
| stack damper | opening | ↑ | ↑ |
| | closing | ↓ | ↓ |

Some of the slides have a written description, often accompanied by pictures. For example, Figure 6 shows the potential consequences of improper draft in a process heater. The students can read the information, which in this case also shows some pictures from actual heaters that relate to the information.

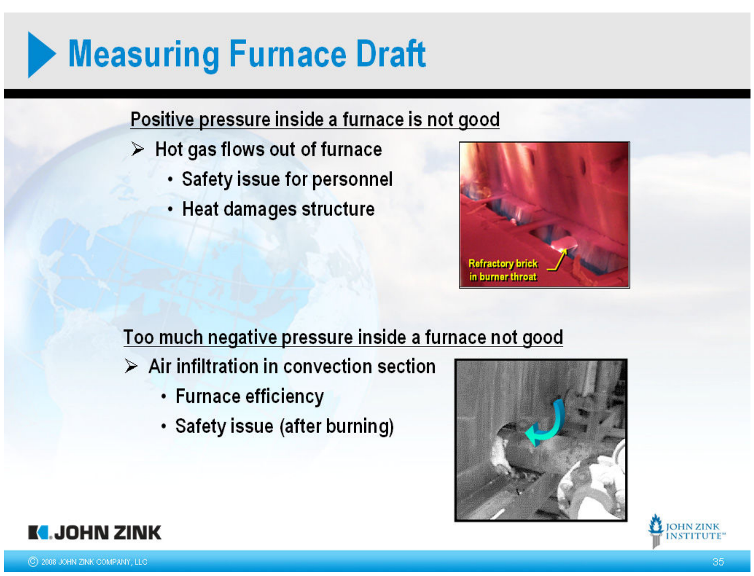



Figure 6. Slide showing the potential consequences of improper heater draft.

Aural Teaching Methods

Lecture is the primary style used by the instructors who verbally explain the concepts, in conjunction with the presentation slides, while the students listen. This is the predominant method that most students have been exposed to during most of their previous learning experiences. While this may not be a particular learner's preferred learning style, it is one that all students need to be at least comfortable with because it is the preferred method used by most teachers. Despite its ubiquity, there is a wide range of lecture techniques. A team of instructors are used during this course, so students are exposed to a variety of voices and speaking styles. Some instructors prefer to remain behind a podium and speak with little voice inflection. Long periods of this can make it difficult for even aural learners to stay focused and engaged. Other instructors prefer to move around the classroom and vary their tone and pitch to make it easier for students to pay attention and learn. The latter is the preferred method to teach the concepts of excess $O_2$ and draft.

Another instructional method that was incorporated which benefits aural learners is the use of video clips of actual operating equipment. Some of these clips demonstrate the various sounds that burners make. For example, students can hear the sounds of burners that are not operating properly, such as burners that are flashing back or huffing.

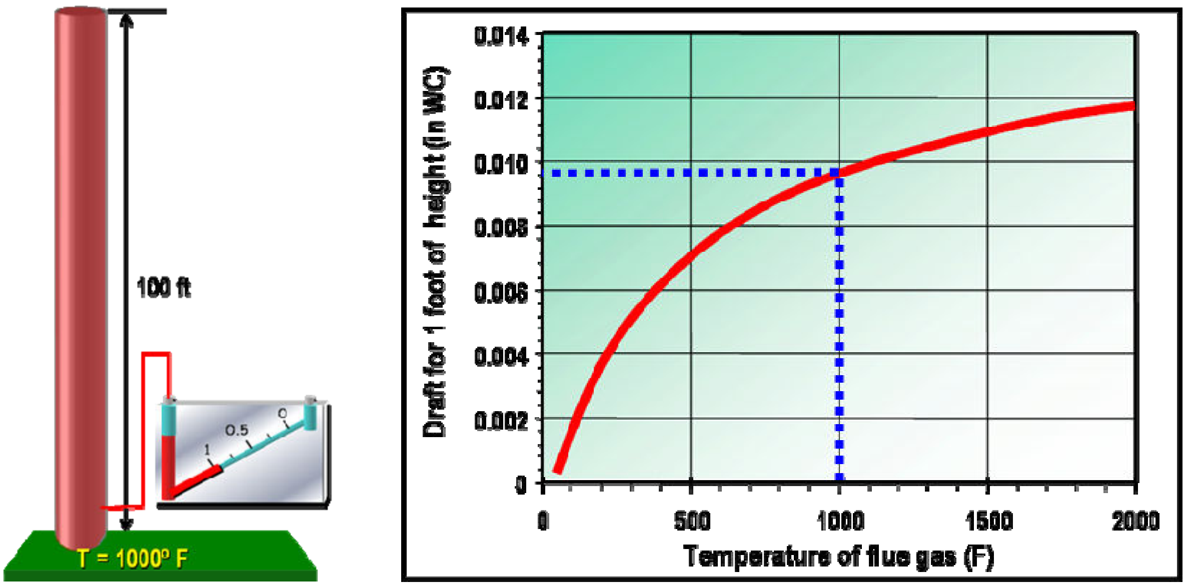
Interactive Teaching Methods

The instructors teaching the concepts of excess $O_2$ and draft normally use the Socratic technique of asking students specific questions to determine their level of understanding and to promote interaction in the classroom. For example, an instructor asks the students which of the three heater configurations shown in Figure 7 would create the most draft and then asks them to explain why. The answer is (c) because higher temperatures and taller stacks create more draft.


(a) (b) (c)

Figure 7. Process heaters: (a) at 1800°F with a short stack, (b) at 1800°F with a tall stack, and (c) at 2100°F with a tall stack.

There are also some problems that students are asked to solve to check their understanding of the class material. An example is shown in Figure 8 where students are asked to discuss how they would calculate the draft that would be created at the bottom of a 100-foot tall stack with exhaust gases at 1000°F, using the chart provided. The graph is the calculated draft per foot for a specific flue gas composition. They simply need to look up the draft per foot for the given temperature, and then multiply it by the height of the stack. The point of the exercise is not the specific answer, but to demonstrate that the higher the temperature and the taller the stack, the more draft created.




(a) (b)

Figure 8. Sample draft calculation for (a) a 100' stack with exhaust gases at 1000°F using (b) chart showing draft per foot of height for a specific flue gas composition at various temperatures.

Figure 9 shows a slide with a schematic of a process heater and three possible locations for measuring excess $O_2$. Students are asked to decide which is the best location and why. Measuring the excess $O_2$ at the floor is problematic because the combustion products may not be well-mixed at that location to give a representative reading. Measuring in the stack would include the tramp air leaking into the convection section (which tends to have high air leakage because of the tubes penetrating through the shell) and not the actual excess $O_2$ levels in the radiant section. The best location is at the top of the radiant section (often referred to as the arch or bridgewall) just before the convection section where the gases are well-mixed and where tramp air leakage should be minimal. This location is also preferred because it is where the draft should be measured as well so a single probe can be used. Students are also asked where excess $O_2$ and draft are measured in their heaters. Surprisingly, they are often being measured at some other location so the probe should be moved, which again underscores the need for this training.

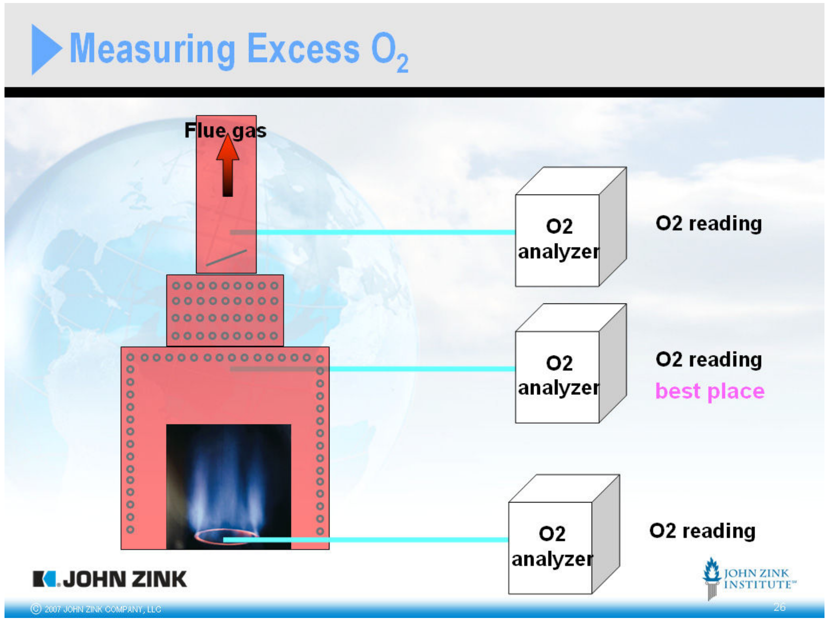
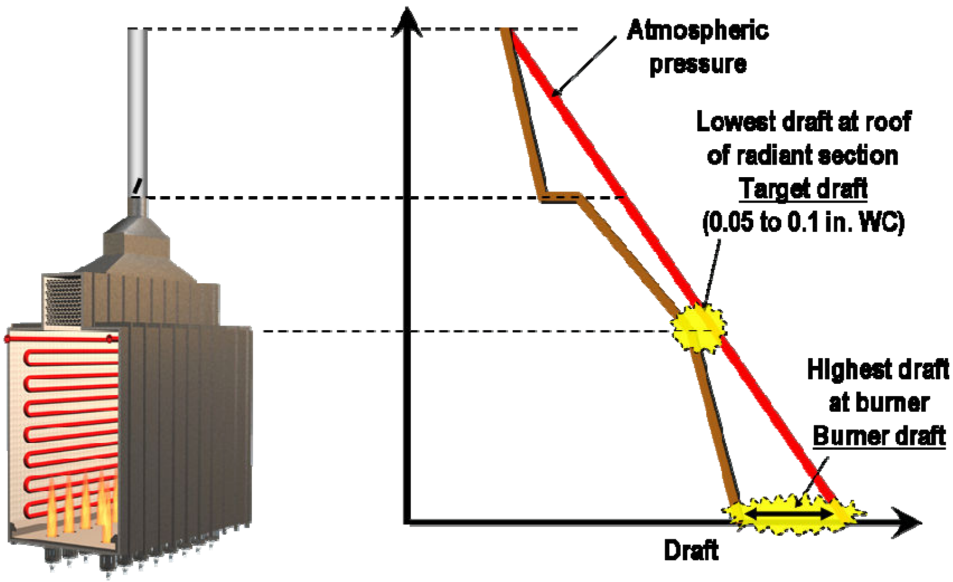



Figure 9. Slide showing multiple possible locations for measuring excess $O_2$ in a process heater, where the arch (top of the radiant section) is the best place.

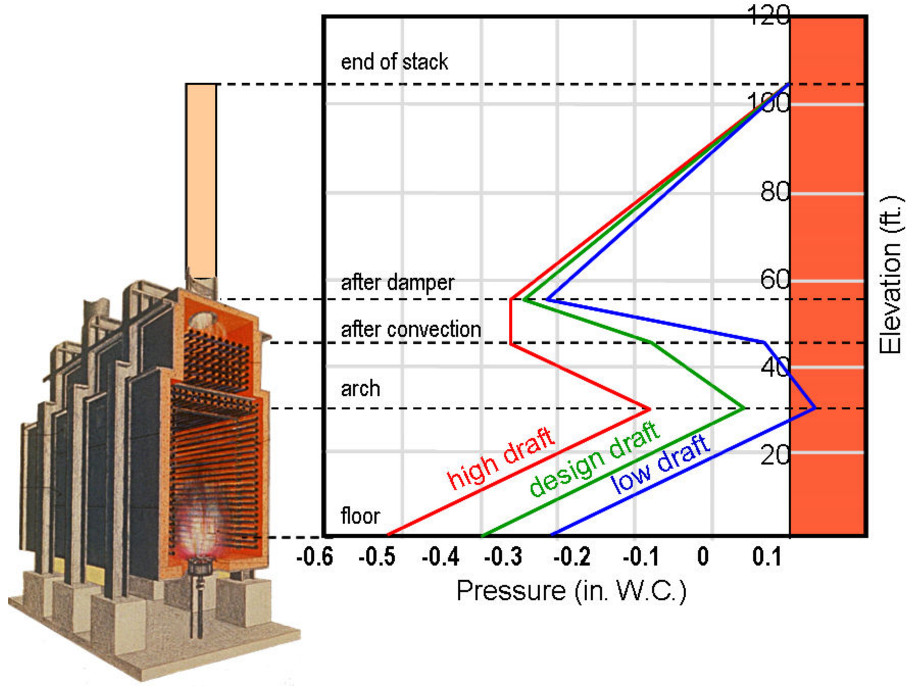
Visual Teaching Methods

Many different visual illustrations are used to explain various aspects of draft and excess $O_2$. For example, Figure 10a shows a trend of how draft varies with elevation inside a typical process heater. The two most important locations to measure draft are at the floor (burner draft) and at the arch (target draft). The available burner draft is used to size the throat of the burner to ensure enough air can be pulled through the burner for the given operating conditions including fuel composition, firing rate, and excess air level. The lowest draft level in the heater is at the arch. It is even possible for the draft to go positive at the arch, which causes hot gases to leak out of the heater. This could cause damage to equipment and injury to personnel.

Figure 10b shows examples of high, normal, and low draft operations. High draft indicates there is too much negative pressure or suction inside the heater. A heater that operates with a high draft level is more susceptible to air leakage or tramp air as compared to one operating at the target draft level. Too much draft can lead to detrimental effects to the heater performance and structure. While the excess $O_2$ levels measured at the arch may be within acceptable limits, much of the air may not have come through the burners due to high infiltration levels of tramp air. If this situation occurs, the burner flames may be unacceptable because not enough of the air for combustion is passing through the burners as designed. This could create high concentrations of CO and NOx, as well as extraordinarily long flames that could impinge on the process tubes resulting in a tube rupture. Low draft indicates that the heater pressure may be positive at the arch, causing hot gases to leak out at that level. The graph visually shows what can happen if the draft is not properly set.




(a)




(b)

Figure 10. Draft variation with elevation in a process heater.

Sparkes (1999) discusses the importance of teaching scientific concepts in conjunction with everyday concepts.[10] Figure 11 shows a common household example using a vacuum cleaner to help explain the effects of closing the burner or stack damper in a process heater. If the vacuum hose is pinched near the inlet to the canister, then the suction and flow are reduced. This simulates closing the stack damper, where both the draft and excess $O_2$ decrease because the flow decreases. If a hand is placed over the inlet of a vacuum cleaner, the suction increases while the flow decreases. This simulates closing the burner damper which increases the draft while reducing the excess $O_2$.

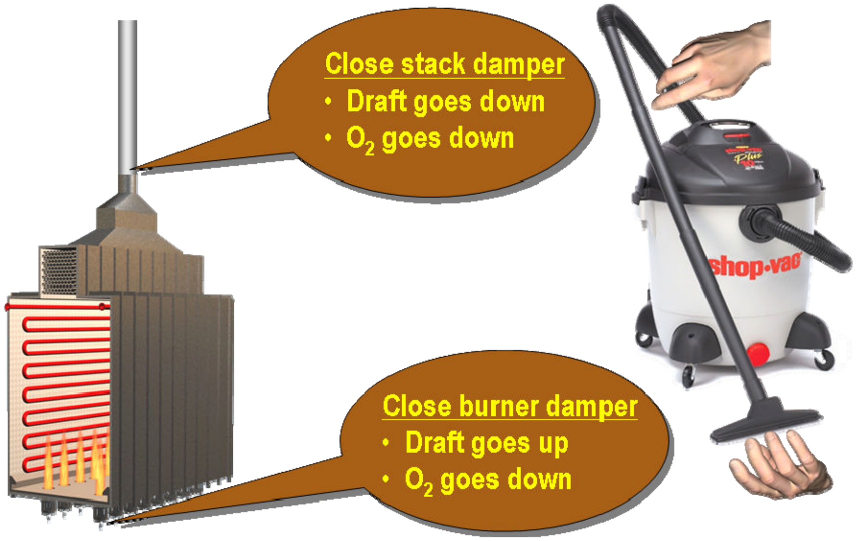



Figure 11. Using a vacuum cleaner analogy to explain how closing the burner damper and the stack damper affect $O_2$ and draft.

Figure 12 shows an example screen from a heater simulator that was developed primarily as a teaching tool. The simulator has numerous inputs that can be varied to demonstrate the effects of a variety of parameters related to fluid flow, heat transfer, thermal efficiency, pollution emissions, and operating conditions. There are also numerous outputs, which have been limited in the screen shown to focus on specific topics – in this case excess $O_2$ and draft. The example shown is for a simulated refinery fuel consisting of 50% $CH_4$, 25% $C_3H_8$, and 25% $H_2$ at 30 psig supply pressure. The burner and heater design parameters were set on another screen. The default positions for the burner and stack dampers are wide open (100%). They are both adjusted so the excess $O_2$ and draft at the arch are approximately 3% (dry basis) and -0.1" water column, respectively. Students see how both variables are affected by changes in the positions of the dampers. If the $O_2$ level gets too low, a warning pops up on the screen stating that the heater is running out of air. Using a simulator is not only safer than making adjustments on an operating heater, it is also much faster and easier for instructional purposes. Real heaters sometimes take 15 minutes or more to react to changes in damper positions, while the simulator reacts immediately. Also, noise levels are often high around operating heaters making it difficult to communicate with a group of students, which is not the case using a simulator in a classroom.

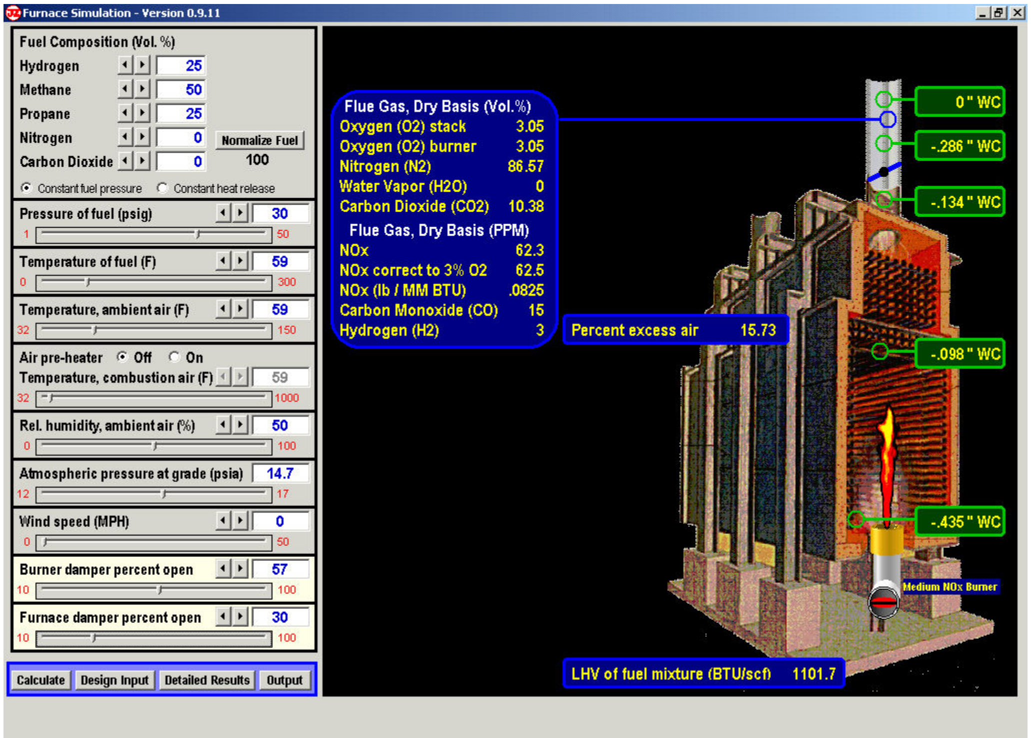



Figure 12. Example screen from heater simulator.

## Assessment

An assessment of the instructional methods described here was not done. The changes were made gradually over a period of several years while other changes were also being made, so it is difficult to assess the specific impact of the changes described here. While pre- and post-tests were given for the course to measure what was learned, data were not collected on the specific questions affected by the changes, so test scores alone are not appropriate measures of effectiveness. In addition, the tests and test questions also changed during the implementation period, further complicating assessment of the improvements. While a formal assessment was not done, an informal survey of the instructors showed that students had far fewer questions about excess $O_2$ and draft after the implementation of the instructional methods described here.

## Conclusions

Continuing education for engineers in HPI/CPI plants often includes process heater operation. Excess $O_2$ and draft in a heater are critical variables that impact the safety, efficiency, productivity, and pollution emissions of the process. These variables are interrelated and are controlled using the burner and stack dampers. Teaching the how and why of controlling these variables can be challenging because they are not always intuitive and there are many other related factors that need to be considered.

Due to the range of preferred student learning styles, a variety of techniques have been developed to teach these concepts in a continuing education course. The four learning styles specifically considered here to teach those concepts include print, aural, interactive, and visual. For learners who prefer print, a textbook and student manual with color copies of the presentation slides are used. For aural learners, lecture and video clips are used. The Socratic method and classroom problems are used to engage students who prefer interactive learning. Illustrations, video clips, and analogies to common phenomena are used for more visual learners. While a formal and rigorous assessment of the instructional methods described here was not done, instructor feedback shows they have been very effective in enhancing learning of what previously had been topics that were often difficult for students to understand.

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