To see the invisible – open-ended university thermodynamics labs with infrared cameras

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Abstract— Thermal imaging with an infrared (IR) camera provides a real-time, holistic image of thermal energy transport. In this workshop, we engage with open-ended laboratory exercises where IR cameras give added value to the understanding of central concepts in second year university thermodynamics courses for physics and engineering students.

Index Terms—Engineering education, thermal sensors

I. LABORATORY EXERCISES IN THERMODYNAMICS

In traditional expository labs, students usually follow a given procedure to reach a predetermined outcome in a cookbook fashion [1]. Expository labs are suitable for attaining certain learning goals, such as mastering advanced laboratory equipment and procedures. Although, if the goal is for students to put their creativity to test or develop conceptual understanding, a more open-ended approach might be worth considering [2]. These include inquiry approaches, guided by students’ own questions, or discovery and problem-based approaches, where students are given more autonomy in how to investigate predetermined phenomena. The challenge is to provide just the right amount of guidance in written instructions and in student-teacher interaction, without taking away students’ ownership of their learning.

II. IR-CAMERA ENHANCED EXERCISES

Below, we show a few examples of open-ended IR-camera-enhanced laboratory exercises from our courses. The development of the exercises has been informed by educational research in the field [3-6].

A. Functionality of heat pumps

A heat pump allows heat transfer from a system of lower temperature to a system of higher temperature – against its spontaneous direction – by performing work. The process of heat transfer from a colder object to a warmer object is readily recognized by students as the functionality of a refrigerator. This exercise involves a heat pump with two buckets of water that correspond to the heat reservoir and heat sink. A good overview of components and processes is attained with a thermal camera, see Figure 1.

![Fig. 1 - A heat pump with a compressor in the center with a low temperature heat source (evaporator) to the left and a high temperature heat sink (condenser) to the right. The work of the compressor transfers heat from the cold to the warm side.](image)

B. Entropy changes in rubber bands

Entropy is a concept in thermodynamics that is usually challenging for students to grasp. In a typical metal, a temperature increase yields an expansion, due to the energy added to the crystalline bonds which thereby relax. In contrast, increasing the temperature of an elastic rubber band yields a counterintuitive decrease in volume, it contracts. The polymer molecules behave as springs with a spring constant that increases with temperature. In this exercise, IR cameras offer the opportunity for precise measurement of the surface temperature of the rubber.

C. Cooling with Joule-Thompson throttling

Joule-Thomson cooling (commonly known as throttling) occurs when a fluid is forced through a porous plug or valve, and allowed to expand adiabatically, i.e. with no heat exchange with its surroundings. This can be demonstrated by releasing gas from a CO₂ fire extinguisher, upon which both the container and the air in which it expands decrease in temperature (see Figure 2). This effect is caused primarily by the phase change from liquid to gas state in the container as the gas is released, during which energy is required to break...
bonds in the liquid CO$_2$. Students often fail to recognise the centrality of the phase change in the process and may need encouragement to move from ideal-gas assumptions to for example a van der Waals model approach.

E. Thermal imaging

One of our most open ended exercises involves investigation of the IR-camera technology itself. What do you see with thermal cameras and what don’t you see? And why is there a striking difference to an ordinary visible light camera? Since the IR cameras can take two pictures simultaneously (see e.g. Figure 4), a thermal as well as a normal photograph, comparisons are commonly made between the two to understand the differences between them. Students tend to study windows, the functionality of which is to let through electromagnetic radiation in the visible spectrum, but reflect heat radiation in the infrared range.

D. Emitted thermal radiation

Thermal radiation can be detected either by a pyrometer or a thermal camera. To investigate the properties of thermal radiation, students are generally referred to start with a Leslie’s cube (see Figure 3). This is a metal cube with uniform internal temperature, typically from a lamp or boiled water, whose surfaces have different material properties. In our lab, there are thermometers, pyrometers and thermal cameras available for students to make comparisons. Thermal cameras have the benefit of measuring an entire area at once, so that for example reflections of thermal radiation from objects in the surroundings will be visible.

III. SUMMARY

We have found IR cameras to be useful in relation to a wide range of thermal phenomena. With its explicit focus on visualisation of heat radiation and temperature, an IR camera inherently turns students’ attention to thermal aspects of the surrounding world. We thereby agree with Xie and Hazzard that the technology is particularly well suited to open-ended, inquiry-based approaches to student labs [4]. However, the technology can also be used in conjunction with more closely...
guided approaches, such as predict-observe-explain, or students’ projects running for an extended length of time [5].

Secondary students have been found to use IR cameras largely as a temperature measurement device [5]. Our experience with university students, in contrast, is that they rather use IR cameras to investigate thermal properties of different materials as they interact with electromagnetic radiation at different wavelengths.

IV. OUTLINE AND PROSPECTS FOR THE WORKSHOP

We want this workshop to have implications for the future engineering education practice of the participants. The idea for the workshop is to show the participants how an open-ended laboratory exercise can be performed with little participant preparation. It will be shown how a thermal camera can be useful for students to develop their conceptual understanding in the thermal domain.

The workshop will consist of two distinct parts.

A. Introduction to thermal imaging

The basic functionality of thermal cameras will be quickly introduced so that the participants know how to use them.

B. Smorgasbord of laboratory exercises

All exercises described above can be tested by the participants or demonstrated by the authors upon request. Thermal cameras will be available to test the concepts that come up during discussions.

REFERENCES