EVERYDAY EXAMPLES OF ENGINEERING CONCEPTS

F6: Energy

This is an extract from 'Real Life Examples in Fluid Mechanics: Lesson plans and solutions' edited by Eann A. Patterson, first published in 2011 (ISBN:978-0-9842142-3-5) which can be obtained on-line at www.engineeringexamples.org and contains suggested exemplars within lesson plans for Sophomore Fluids Courses. They were prepared as part of the NSF-supported project (#0431756) entitled: "Enhancing Diversity in the Undergraduate Mechanical Engineering Population through Curriculum Change".

INTRODUCTION

(from *'Real Life Examples in Fluid Mechanics: Lesson plans and solutions'*)

These notes are designed to enhance the teaching of a sophomore level course in fluid mechanics, increase the accessibility of the principles, and raise the appeal of the subject to students from diverse backgrounds. The notes have been prepared as skeletal lesson plans using the principle of the 5Es: Engage, Explore, Explain, Elaborate and Evaluate. The 5E outline is not original and was developed by the Biological Sciences Curriculum Study[1] in the 1980s from work by Atkin & Karplus[2] in 1962. Today this approach is considered to form part of the constructivist learning theory[3].

These notes are intended to be used by instructors and are written in a style that addresses the instructor, however this is not intended to exclude students who should find the notes and examples interesting, stimulating and hopefully illuminating, particularly when their instructor is not utilizing them. In the interest of brevity and clarity of presentation, standard derivations, common tables/charts, and definitions are not included since these are readily available in textbooks which these notes are not intended to replace but rather to supplement and enhance. Similarly, it is anticipated that these lesson plans can be used to generate lectures/lessons that supplement those covering the fundamentals of each topic.

It is assumed that students have acquired a knowledge and understanding the following topics: first and second law of thermodynamics, Newton's laws, free-body diagrams, and stresses in pressure vessels.

This is the fourth in a series of such notes. The others are entitled 'Real Life Examples in Mechanics of Solids', 'Real Life Examples in Dynamics' and 'Real Life Examples in Thermodynamics'. They are available on-line at www.engineeringexamples.org.

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[1] Engleman, Laura (ed.), *The BSCS Story: A History of the Biological Sciences Curriculum Study*. Colorado Springs: BSCS, 2001.
[2] Atkin, J. M. and Karplus, R. (1962). Discovery or invention? *Science Teacher* 29(5): 45.
[3] e.g. Trowbridge, L.W., and Bybee, R.W., *Becoming a secondary school science teacher*. Merrill Pub. Co. Inc., 1990.

FLUIDS IN MOTION

6. <u>Topic</u>**: Energy**

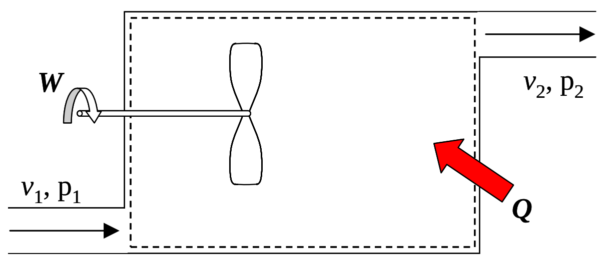
Engage:

Take a portable forced air heater into class. The type most students have in their rooms. Set it up on the desk at the front of class and make a show of warming your hands in front of it. Ask students, working in pairs, to identify the energy transfers being made to the air passing through the fan-heater and then to incorporate them into a control volume diagram.

Explore:

Invite one group to list the energy transfers that they identified. Discuss how these transfers relate to the first law of thermodynamics, i.e., conservation of energy with electrical energy being converted into heat energy and mechanical energy then the later being transferred as kinetic energy to the air.

Invite a second group to sketch their control volume on the board for the class to see. Discuss how we can include energy flows as well as mass flows. In this case, mechanical work, *W*, via the fan and heat transfer, *Q*, from the heating elements.



Explain:

Explain that there is energy contained in the mass flows into and out of the fan-heater, so that these represent energy transfers across the control volume boundary as well as the mechanical or shaft work and the heat transfer from the heater. The energy of a mass of fluid has three components:

a. internal energy due to the activity of the molecules;

b. kinetic energy due to the motion of the fluid; and

c. potential energy of the fluid as a result of its position (height).

Expand on this by explaining that the first law of thermodynamics can be employed to track or account for these energy transfers and that in this context it is known as the steady flow energy equation. It can be stated in words as '*for any mass system, the net energy supplied (in) to the system equals the increase of energy of the system (stored) plus the energy leaving (out) the system*', i.e.

$$\Delta E = \Delta Q - \Delta W$$

where ΔQ is the net heat transfer into the system, ΔW is the net work supplied to the system, and ΔE is the increase in energy of the system. The Steady Flow Energy Equation (S.F.E.E.) can be derived from this expression by substituting for the three components of the energy (internal, kinetic and potential) in the mass flow to give

$$\dot{m}\left\{(h_2 - h_1) + \tfrac{1}{2}\left(v_2^2 - v_1^2\right) + g(z_2 - z_1)\right\} = \dot{Q} - \dot{W}$$

Elaborate:

Apply the SFEE to the fan-heater to find the enthalpy (internal energy) change experienced by the air. Assume the fan-heater converts 1000W of electrical energy into heat and work to drive the shaft, i.e.

$$\dot{Q} - \dot{W} = 1000\text{J/s}.$$

If the change in elevation between the center of the inlet and the center of the outlet is 100mm, then

$$g(z_2 - z_1) = 9.81 \times 0.1 = 0.981\text{J}$$

Now if the inlet and outlet ports are the same size, then mass continuity demands that

$v_1 = v_2$ so $\tfrac{1}{2}\left(v_2^2 - v_1^2\right) = 0$

If the fan is 110CFM (110×0.000472 = 0.052 m^3/s), then the mass flow rate will be 0.062 kg/s (=1.2×0.052)

Thus rearranging the SFEE to obtain

$$(h_2 - h_1) = \frac{\dot{Q} - \dot{W}}{\dot{m}} - \tfrac{1}{2}\left(v_2^2 - v_1^2\right) - g(z_2 - z_1) = \frac{1000}{0.062} - 0 - 0.981 = 16049 \equiv 16\text{ kJ/kg}$$

This is the energy available to warm the room for you.

Evaluate:

Invite the students to attempt the following examples:

Example 6.1

A new design of hand-dryer generates two 400mph sheets of air at approximately room temperature and about 30cm above the air intake. The mass flow rate is 68 CFM and its manufacturers claim it will dry your hands in 12 seconds. Calculate the work done by the dryer to dry your hands.

Solution:

Apply the steady flow energy equation and assume an ideal gas

$$\dot{m}\left\{(h_2 - h_1) + \tfrac{1}{2}\left(v_2^2 - v_1^2\right) + g(z_2 - z_1)\right\} = \dot{q} - \dot{w}$$

The flow is adiabatic in the dryer (no heat source) so $\dot{q} = 0$ and the air inlet and outlet are at atmospheric pressure so $h_1 = h_2$. The mass flow rate is given by

$$\dot{m} = 1.2(68 \times 0.000472) = 0.0385\,\text{kg/s}$$

Assume that the air intake is large and so the velocity approximates to zero then:

$$\dot{w} = \dot{m}\ \left\{\tfrac{1}{2}v_2^2 + g(z_2 - z_1)\right\} = 68 \times 0.000472\left\{\frac{178.8^2}{2} + 9.81 \times 0.3\right\} = 513\,\text{J/kg}$$

Over a 12-second period the total mass flow will be 0.462kg (=12 × 0.0385); and hence, the work done will be 237J (=0.462 × 513) which is 0.000066 kWh. This compares to the manufacturer's claim of 0.00468kWh per dry!

Example 6.2

The total force opposing the motion of a cyclist is given by[4]

$$R = \frac{C_d \rho v^2}{2} A + C_r m g$$

where v is the rider's speed through the air of density ρ, A is the projected frontal area of the rider and bicycle who have a mass, m, and a drag coefficient of C_d=0.9. Typical values for the product AC_d are of the order 0.39. C_r is the rolling coefficient and is typically 0.003.

For a rider and bike of combined mass 84kg, calculate the work-rate required to maintain a steady speed of 30mph on a level road; then assuming about 18% of energy obtained from food is converted to mechanical energy, estimate the food intake required for a 90-mile bike ride.

Solution:

Take the cyclist and bicycle as the moving control volume, then the SFEE reduces to

$$\dot{Q} - \dot{W} = 0$$

Because there is no change in elevation (z_1=z_2), no change in velocity (v_1=v_2), and no change in enthalpy (h_1=h_2) across the control volume.

The work-rate is the resisting force multiplied by the velocity (13.41 m/s) so,

$$\dot{w} = \frac{\rho A C_d v^3}{2} + C_r m g v = \frac{1.2 \times 0.39 \times 13.41^3}{2} + (0.003 \times 84 \times 9.81 \times 13.41) = 597\ \text{J/s}$$

Now from SFEE we have $\dot{q} = \dot{w}$ so the combustion of calories equals the work-rate once the metabolic efficiency is accounted for, i.e., $\dot{q} = \frac{\dot{w}}{\eta} = \frac{597}{0.18} = 3319\,\text{J/s}$ or about 2880 Calories per hour.

[4] Grappe, F., Candau, R., Belli, A., Rouillon, J.D., Aerodynamic drag in cycling with special reference to the Obree's position, Ergonomics, 40(12):1299-1311, 1997.