Lister Bag Project

Introduction

Especially in hot, dry climates evaporation may be used successfully both for space cooling and for the cooling of drinking water. When used for the latter, a small amount of the potable water is sacrificed to cool that which remains. Typically the water is held in a container whose walls are somewhat permeable. A *Lister bag* is one such device and has been used in military and other outdoor applications. (The Lister bag was named for William *Lyster*, a U.S. Army surgeon who experimented with water purification using sodium hypochlorite (bleach) and developed the original bag just before WW I.) Looking much like a duffel bag with three or four spigots at the bottom, the Lister bag is suspended from a tripod (Figure 1). The cotton duck fabric is sufficiently permeable that the outer surface remains damp, but not so much that the water oozes freely through and drips off.

Figure 1. Lister Bag in use at 1960 Boy Scout National Jamboree in Colorado Springs, CO. (In earlier years the Jamboree was at a different site each time it was held, but now because of the expense in providing the necessary infrastructure, including potable drinking water and sanitation, it always held at Ft. A.P.Hill, VA.)

Ideally the Lister bag would be suspended under a canopy in order to minimize direct solar gain, but should be exposed to the wind so as to enhance convective mass transfer in particular. It is quite likely (and desirable) that the sensible heat transfer will tend to increase the temperature of the water (since the whole idea is for evaporative cooling from the damp surface to lower the temperature of the water below that of the ambient air). If the relative humidity of the ambient air is low enough, the latent heat removed from the wet surface of the bag as the water evaporates will help to lower the temperature of the water remaining in the bag below that of the ambient air and thus make it more refreshing to drink. In this project your job is to set up a spreadsheet with which you can compute the temperature-time history of a typical Lister bag given its dimensions, ambient conditions, etc. and thus be able to explain its operation and make design and operational recommendations.

Learning Objectives

When you have finished this project you should be able to:

1. Explain the difference between sensible and latent heat transfer,
2. Define and calculate the *film* temperature,
3. Explain the significance of the Reynolds, Prandtl and Nusselt numbers in convection heat transfer and identify the driving potential,
4. Determine all necessary fluid properties for this calculation using either the tables in the textbook or supplied Excel functions,
5. Compute the convective heat transfer coefficient for a cylinder in crossflow using a standard correlation and from that, the sensible heat transfer,
6. Explain the significance of the Reynolds, Schmidt and Sherwood numbers in convective *mass* transfer and identify the corresponding driving potential.
7. Compute the convective mass heat transfer coefficient for a cylinder in crossflow using a standard correlation and from that, the evaporation rate and the latent heat transfer,
8. Display, verify and interpret the results predicted by your calculations.
9. Test parameters readily and, on the basis of your calculations, explain the physics of evaporative cooling and propose strategies to maximize the cooling effect.
10. Justify the use of a "lumped capacitance" approach to a system involving a mobile fluid instead of the more usual highly conducting solid.

Formulation and Implementation of the Problem

A spreadsheet provides an excellent platform on which to develop this project since there are a number of calculations that will need to be done at each of many increments in time. Thus a general outline of this spreadsheet would include input data at the top followed by a table in which time runs down the rows. Each column will contain results from one of the several calculations that need to be done at each time step. As suggested in the Sweaty Runner project (pp 58-59 in studio manual) you should "name" the cells in which you place input data, e.g., the cylinder diameter, ambient air temperature, relative humidity, etc., so that in subsequent cell formulae you can reference them not by obfuscating cell addresses, but by variable names that make sense! Since Visual Basic for Applications (VBA) functions for all the necessary air and water properties as a function of temperature are readily available there, you should start with the

Airwater.xls workbook. Just begin your Lister bag calculations on another worksheet in that same workbook.

As with the Sweaty Runner project you'll want to set up columns for each of the intermediate calculations that need to be done at each time increment. In addition you should program up your own VBA function for the Churchill and Bernstein correlation (See manual pg. 59) since: (1) it is pretty messy to implement as a cell formula, (2) you can use it a second time when you are ready to compute the mass transfer. Add your own VBA coding to those functions already provided for the fluid properties.

Assume that the bag is an "infinite" cylinder of diameter 0.4 m and length 1.1 m. These dimensions will give a volume of approximately 36 gallons, the official U.S. Army capacity. Neglect heat and mass transfer from the ends.

The sensible and latent heat transfer at each time step may be computed using the same procedures outlined in the Sweaty Runner proje ct. Here, instead of computing those quantities as a function of the runner's velocity, you will be computing them as a function of the time elapsed since the beginning of the transient.

We will use a very simple approximation for the solar gain. The following values for the maximum Solar Heat Gain Factor (SHGF) for 40°N latitude in August are taken from the ASHRAE 1981 Fundamentals Handbook Chapter 26 Table 11:

Facing South, SHGF-S = 470 W/m^2
Facing North, SHGF-N = 110 W/m^2
Facing East/West, SHGF-E/W = 681 W/m^2

Then, approximating the radiative gain to the cylinder surface by a weighted combination of the SHGF's for the four compass directions, we obtain:

$$q''_{rad} = \left(0.25 SHGF_S + 0.25 SHGF_N + 0.5 SHGF_{E/W}\right)$$
$$= \left[0.25(470) + 0.25(110) + 0.5(681)\right] = 485 \frac{W}{m^2}$$

Now having computed the net heat transfer (W), including direct solar gain, sensible convective gain (loss), latent convective gain (loss), you can equate that total to the rate of change of energy stored:

$$q_{net} = \frac{dE}{dt} = r c_p V \frac{dT}{dt},$$

which, using a simple forward difference approximation for the rate of temperature change, gives for the change in temperature of the water in the bag over the duration of a single timestep :

$$\Delta T = \frac{q_{net}\,\Delta t}{r\, c_p V}$$

With the large heat capacity of the water in the bag and a timestep of about 0.10 hours (6 min.), you should not have to worry about numerical instabilities in this calculation even though you are in effect running an *explicit* calculation (since the heat fluxes are all approximated using data at the previous time level). Once you have updated the water temperature, you are ready to go on to the new time represented by the next row.

Things to Think About

1. What is the best way to display your solution, both the dependence of temperature on time and the computed heat fluxes, for your client?

2. How can you check that the numbers you compute are correct? One method is to check and recheck your cell formulae; another is to do the calculation by hand for at least one set of parameters. What other means can you think of?

3. Why are you justified (or not justified) in treating the water in the bag as a "lumped" capacitance (i.e., all at one temperature)?

4. Would a Lister bag be desirable in a warm, humid environment? (Lister bags were used by U.S. troops during the Vietnam War.)

5. We have included (crudely) the solar (short wavelength) radiative gain in our calculation. What would be the effect of including the long wave (infrared) radiative exchange with the surroundings? Would you expect that mechanism to be important?

6. What happens to the latent heat transfer term if the bag is filled with very cold water on a hot, humid day?

References

1. http://www.armymedicine.army.mil/armymed/about/history/highlights.htm

2. http://www.lejeune.usmc.mil/mces/UIC/BasicHygieneEquipmentOperator/Tactical%20Water%20Distribution%20System%20(TWDS).pdf