A THERMAL INVESTIGATION OF THE RUNNING CHEMICAL REACTOR

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INTRODUCTION

The purpose of this study is to obtain sufficient information concerning the jogger such that better jogging clothing can be designed for his use. To design such clothing, the various terms in the energy balance for the jogger must be well understood, particularly as these terms influence his rate of running and his comfort. Since the energy balance is intimately connected with convective heat and mass transfer, the coefficients for these two processes need to be determined for the various types of clothing being investigated. Therefore, the study has centered on the study of heat and mass transfer coefficients associated with various types of clothing in various types of weather. With these coefficients in hand, it is hoped that the clothing can be designed to maintain near optimal conditions for the jogger. The studies so far indicate that the body temperature must be controlled within certain limits to promote an invigorating run and comfort in the run. At the present time, surface temperatures are being measured and used in both the mass and heat transfer coefficient determinations and as an indicator of the comfort zone for the runner.

ENERGY BALANCE FOR THE RUNNING CHEMICAL REACTOR

Five major terms are involved in the energy balance for the runner. In normal conditions, two terms are adding thermal energy to his system. This energy must then be dissipated through one or all of three mechanisms. Thus, the energy balance has five terms in it as indicated in Equation (1).

$$Q_{int} + Q_{rad} = Q_{evap} + Q_{conv} + Q_{sens} \quad (1)$$

Q_{int} equals the heat being generated internally as the runner propels himself along. This energy, of course, is a function of the weight of the runner. However, the quantity of energy being generated appears to be a linear function of the distance covered. In this case, 110 kcal per mile has been utilized successfully in the energy balances over the past three months.

Q_{rad} equals the energy being deposited on the body by solar radiation. This term can vary from 0 at night up to approximately 500 kcal/hour in a very hot sunny day. The term is difficult to determine. In the earlier studies approximately 238 kcal/hour were used. However, present studies indicated that the term can go much higher as the above figures indicate. A simple solar collector has been utilized to determine the quantity of energy deposited on the surface of the earth. In addition, energy balance, Equation (1), has been utilized to give good values for Q_{rad} if all of the other terms of the balance are reasonably well known.

Q_{evap} equals the energy removed from the body by the mass of water evaporated during the run. The evaporation can occur from the external surface of the body or in the air being inhaled and exhaled from the lungs. At the body surface temperature of approximately 85 to 88F, the change in enthalpy per pound of water is 265 kcal. In a one-hour run up to four and one-half pounds of water have been lost, and, therefore, approximately 1200 kcal can be lost per hour by evaporation.

Q_{conv} equals the energy lost from the body (sometimes gained in very warm weather) by thermal convection. The basic equation is shown in Equation (2),

$$Q_{conv} = h_T \cdot A \cdot (T_{surface} - T_{air}) \cdot t \quad (2)$$

This term varies greatly. In warm weather it is approximately zero; in very cold weather it can increase to 500 to 700 kcal/hour. Some of the cold weather runs have given good indications of the heat transfer coefficient.

Q_{sens} equals the energy being deposited in the air that is heated by the lungs. This energy varies, of course, with the outside temperature. For warm weather, it is approximately 0; for cold weather it can increase to around 50 kcal/hour.

In addition, the evaporation mass transfer can lead to the calculation of a mass transfer coefficient as shown in Equation (3).

$$M_{evap} = k_{mt} \cdot A \cdot (H_{surf} - H_{air}) \cdot t \quad (3)$$

k = mass transfer coefficient in lbs(air)/(h·ft^2); H = the humidity either at the surface or in the air in lbs(H_2O)/lb dry air.

EXPERIMENTAL TECHNIQUE

The jogger being studied collects a large amount of easily measured data on each run. The data so collected are as follows:

- Weight before and after run, nude and dressed
- Rates of running: Measured mile times for each mile (Eight miles each day)
- Wind velocity and direction; atmospheric pressure; percentage of sun
- Temperature and humidity (by wet bulk measurements)
- Amount of moisture in each article of clothing
- Rate of breathing
- Length of stride
- Surface temperature of torso and legs

In addition, solar radiation measurements are made by measuring the amount of water evaporated from a black cloth exposed to the incident solar radiation. The cloth is contained in an eight-inch diameter bowl.

These data allow calculations of various components of the energy balance. The most critical for accurate measurement is the actual water loss by evaporation.

SURFACE TEMPERATURE MEASUREMENTS

The above analysis is very dependent upon good measurements of the surface temperatures of the body. Actually, each part of the body has varying temperatures, and a total analysis is, therefore, quite impossible.

However, two temperatures are being measured regularly. Usually the placement of the thermistor for the temperature measurement is on the chest area at the bottom of the rib cage and on the thigh about three inches above the knee. These thermistor placements give an indication of the temperature of the upper torso and the area of the legs below the waist. The exciting part of the temperature study indicates that these temperatures are very dynamic in their performances. The upper torso temperatures have been measured all the way from 34°C down to 22°C. The leg temperatures have been measured from 34°C down to 13°C. For efficiency of running and comfort, the upper torso should be maintained somewhere between 25 and 30°C. Temperatures after steady state is reached above 30°C tend to slow the run and also lead to discomfort. Temperatures below 25°C for the upper torso also lead to discomfort and tend to slow the runner. The lower body temperatures, below the waist, do not seem to affect the runner and his performance. In most of the runs during this study, the jogger wore shorts and the legs were bare. The legs tend to take on a level of temperature which will help to bring the body energy balance into equilibrium. More data are required to understand the phenomena of the dynamics of the various surface temperatures. However, the recent measurements indicate that the leg temperatures can go above or below the measured temperatures of the upper torso. The evaporation rates greatly influence these two temperatures. Since more water is usually available on the upper torso, the torso temperatures sometimes can drop substantially while the leg temperatures do not drop.

RESULTS OF HEAT AND MASS TRANSFER STUDIES

Heat and mass transfer coefficients have been determined for various clothing configurations. In almost all cases, shorts were worn. However, the upper torso has been covered by a variety of clothing devices, such as simple T-shirts all the way to complicated jogging jackets which are impervious to water transport. So far, some of these jackets and clothing appear to be more beneficial than others. However, for consistent understanding of these types of clothing, the mass transfer and heat transfer coefficients have to be quite well defined. The mass transfer coefficients range from 5-22 lb(air)/($ft^2 \cdot h$) and the heat transfer coefficients from 0.5 to 1.5 kcal/($h \cdot ft^2 \cdot °F$).

Some clothing combinations appear to produce the correct level of surface temperatures for the upper torso. For instance, in very warm weather (80-90°F) at the present time a net shirt appears to be a better type of covering than even a bare chest as far as keeping that surface in temperatures near 25°C. In the winter, where temperatures were 40 to 50°F in Gainesville, the impervious jacket appeared to give very good results.

USE OF DATA TO DESIGN CLOTHING

Once the various heat and mass transfer coefficients are understood sufficiently they can be utilized to generate the appropriate terms in the energy balance for various types of clothing and for given humidity and temperature conditions. Ultimately, given the temperature and humidity of the day, the rate of running of the jogger or runner, a series of clothing can be suggested and tried by simulation on the computer to determine whether or not a particular configuration suggested will produce a comfortable body condition for the jogger. The criteria for comfort probably will be the surface temperature of the upper torso. At the present time the data are not sufficient to set this temperature range. However, the running results have been surprisingly good for surface temperatures between 25 to 30°C. Possibly the critical temperature is that which is finally obtained in the stabilized pseudo-steady state condition after three to four miles of running.