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by

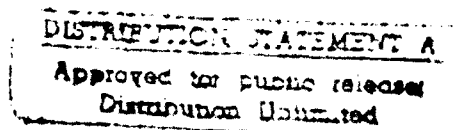
R.J. Oszcewski and J.F. Tremblay-Lutter

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ABSTRACT

A small, battery-powered fan heater charged with dry ice was tested as a possible means to cool personnel in a Canadian Forces casualty bag. The cooling power was measured at about 50 watts, which is about a third of the cooling needed in a hot environment. When the carbon dioxide was allowed to leak into the airspace of the casualty bag, its concentration rose to a level that normal individuals would find uncomfortable, but not toxic.

RÉSUMÉ

Un petit ventilateur à chauffage muni d'une pile et rempli de neige carbonique fut utilisé dans un sac de protection pour la transportation de soldats gravement blessés. Un refroidissement de 50 watts fut obtenu. Cependant, afin de refroidir suffisamment un soldat blessé dans un environnement à température très élevée, au moins trois fois plus de refroidissement serait nécessaire. La concentration de CO₂ qui sécoula du ventilateur placé entièrement dans le sac n'était pas toxique mais serait inconfortable pour des individus non-blessés.

EXECUTIVE SUMMARY

A Heatpac™ personnel heater was used to cool the air in a Canadian Forces chemical protective casualty bag. Dry ice replaced the usual charcoal fuel element. In a room temperature experiment this cooling unit provided about 50 watts of cooling for a period of just less than one hour. In a hot (50°C) environment it is predicted that it would provide about 65 watts for a period of about 45 minutes. Although this is equal to the heat produced by the body, it is not enough. The environmental heat load of a hot desert environment is at least as great as the metabolic load. The cooling power cannot be increased by using more than one cooling unit without increasing the hazard from the accumulation of CO₂ in the event of leaks.

When the CO₂ from one cooling unit was allowed to leak into the airspace of the casualty bag, the CO₂ concentration reached 5%. This level is uncomfortable but not toxic for normal individuals. Since it is possible that elevated CO₂ concentrations will have adverse effects on a casualty, this gas should normally be vented outside the bag. A value for the resistance of the casualty bag to the diffusion of CO₂ was determined from the experiment and generally confirmed by the results of other trials.

Without active auxilliary cooling, casualties must evaporate sweat to avoid rapid onset of heat injury. However, they may not be able to sweat if they are severely dehydrated, burned or have received certain medications, and if the environment is humid, only a small fraction of any sweat produced will evaporate. At least 130 watts of cooling will be required in hot environments to prevent heat injury.

INTRODUCTION

Given an adequate supply of water, most heat acclimatized and healthy soldiers will be able to adjust to hot desert conditions. A casualty will have a much harder time, especially if totally enclosed in a bag for protection against chemical agents. During the Gulf War, expedient measures were sought to provide some cooling for casualties. One suggestion was to use solid carbon dioxide (CO_2), i.e. dry ice, as a refrigerant in the Norwegian personnel heater [HEATPAC™, Standard Telefon og Kabelfabrik, Oslo, Norway]. Normally this device is used to provide heat in cold environments by burning charcoal fuel elements in a combustion chamber (1) (Figure 1).



FIGURE 1. HeatPac™ and casualty bag.

For cooling, dry ice can be used in place of the charcoal fuel element. A small fan in the heater, powered by a D-cell, draws air around the combustion chamber. The air is cooled by the dry ice and sent back into the airspace of the casualty bag. CO₂ evaporates, leaves the combustion chamber and passes through an exhaust tube to the outside. An experiment was carried out to determine the refrigeration power of this cooling unit and to determine the level of CO₂ that would be reached if the device leaked into a casualty bag.

METHOD

The Canadian Forces casualty bag for a chemical warfare environment is made from a charcoal-impregnated, open-cell foam laminated to a cotton/nylon outer shell. It has an internal framework that supports the top of the bag near the head, creating an airspace around the occupant's head and chest. It has a flexible plastic window above the casualty's face. In the experiment a headless plastic mannikin was inserted into the casualty bag so that the bag would assume the same shape as it would in actual use. An electronic scale with an L.E.D. display was placed inside the bag where the head of the mannikin would normally have been. The Heatpac™ personnel heater was converted to a cooling unit by packing the combustion chamber with 236 grams of pulverized dry ice. It was then placed on the pan of the scale and arranged so that the fan directed the cooled air toward the mannikin's chest. The exhaust tube of the cooling unit was removed to simulate a worst-case accidental leak into the bag. The rate of sublimation of dry ice was determined from the changes in the mass of the cooling unit, read from the scale through the casualty bag window.

The air in the space at the head of the casualty bag was continuously sampled (175 ml/min) and the concentration of CO₂ measured with an Ametek Carbon Dioxide Analyzer, model CD-3A. The sample was returned to the airspace so that the sampling pump would not create a net pressure difference and cause outside air to be drawn into the bag. The concentration of carbon dioxide and the mass of the personnel heater were recorded at intervals of one minute.

RESULTS

When the casualty bag was closed, the concentration of CO₂ in the air space at the head of the bag rose rapidly (Figure 2). In seven minutes it reached an approximate steady state that was maintained for another twenty minutes. The concentration of CO₂ during this period varied from 4.0 to 4.15%. After fifty-one minutes the concentration had fallen to 3% and the test was halted.

After six minutes (Figure 3), the rate of sublimation of carbon dioxide had levelled off at 0.08 g/s. This rate was

maintained for about twenty minutes. At the end of the test, 93% of the dry ice had evaporated. Given the sublimation rate at that time, the rest would have vapourized by the end of the hour. The mean sublimation rate was approximately 0.07 g/s. These rates have been corrected for the 10 g of water-ice that accumulated in the combustion chamber during the test.

The cooling power was calculated from the sublimation rate of the dry ice, assuming that the heat absorbed in vapourizing a gram of solid CO_2 and warming it to room temperature is 650 joules. One minute from the start, the cooling power was 62 watts. It dropped to 51 watts after six minutes and stayed at that level for about a half hour. The mean cooling rate was 46 watts.

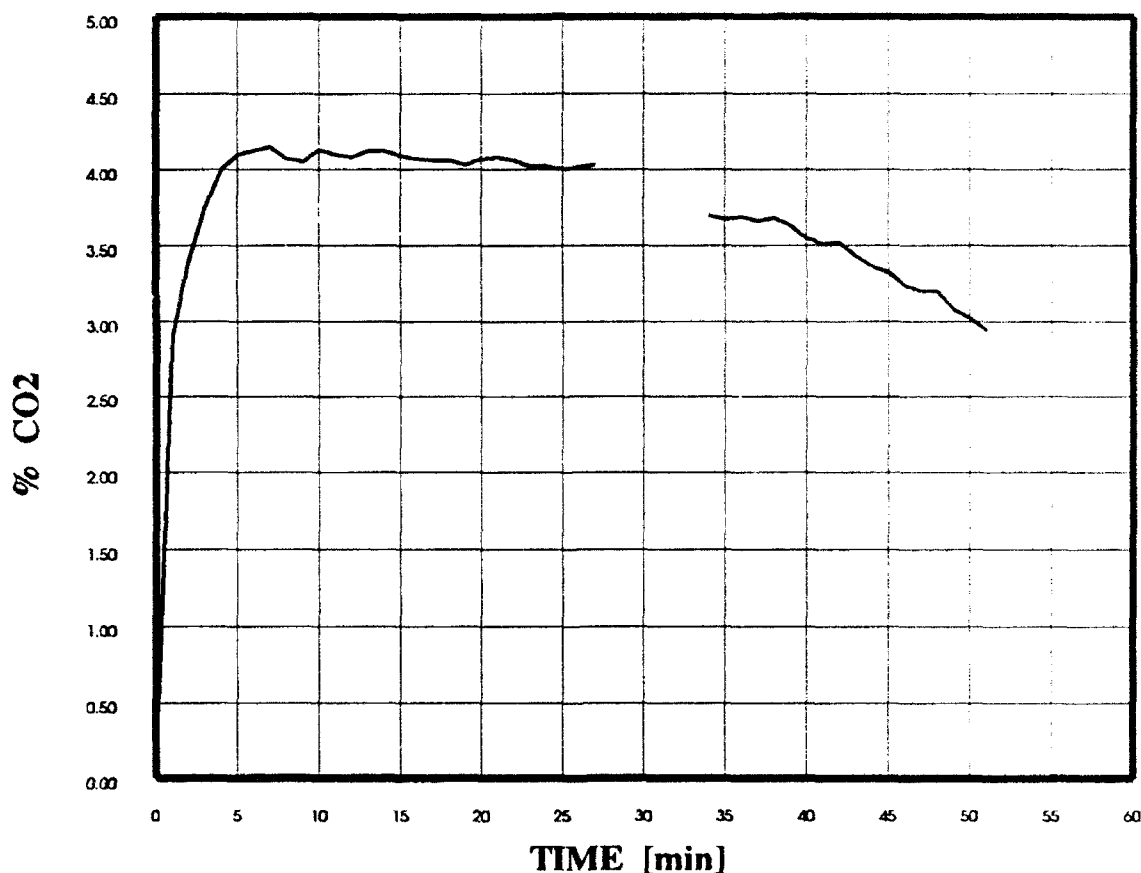


Figure 2. Concentration of carbon dioxide in the casualty bag when the cooling unit discharges into it.

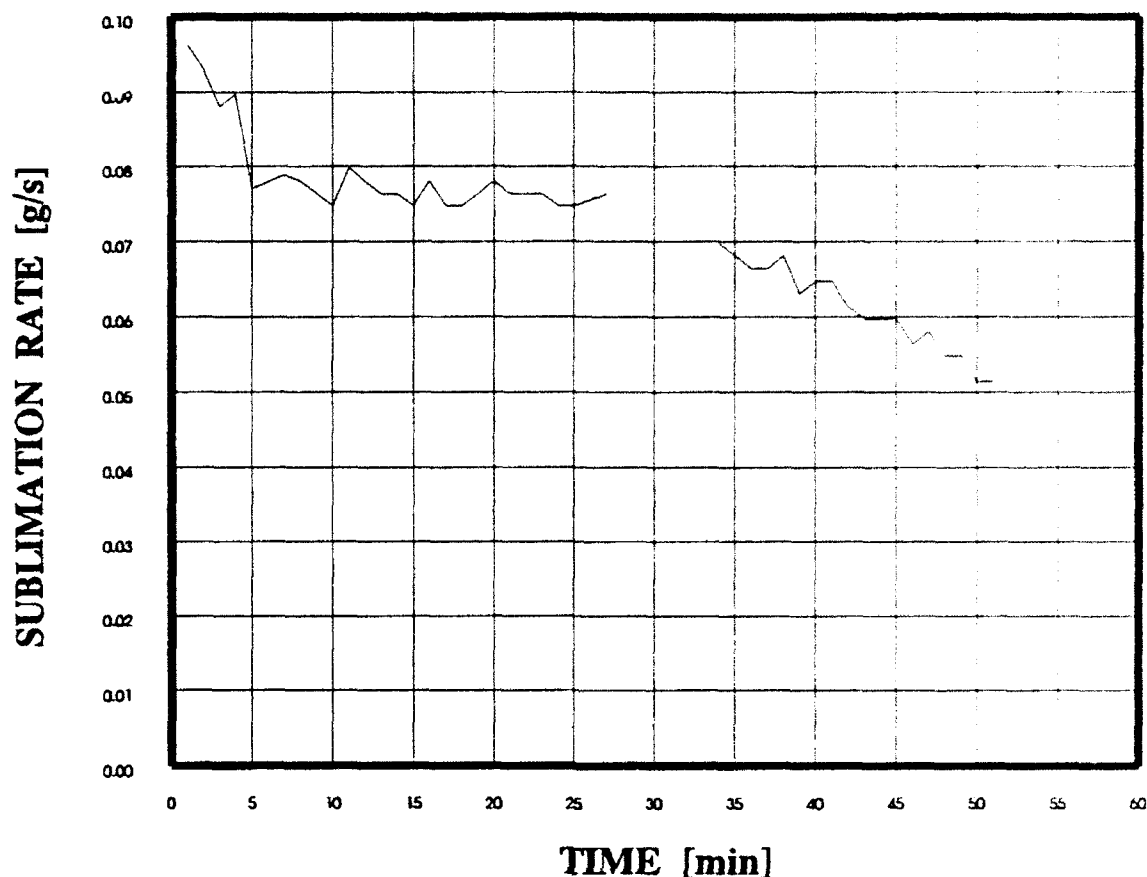


Figure 3. Sublimation of dry ice in the cooling unit.

DISCUSSION

For present purposes, a "CO₂ resistance" can be calculated for the bag as in equation 1.

$$R = (C_{ss} - C_x) / M \quad (1)$$

where M is the rate of production of carbon dioxide in the bag
 C_{ss} is the concentration at steady state and
 C_x is the concentration in the outside air.

Because of the large volume change when solid CO₂ changes to a gas, the pressure inside the bag is slightly higher than atmospheric. A sublimation rate of 0.07 g/s represents a volume change of over 2 litres/minute. Air and CO₂ were therefore driven through the porous shell material at that rate. R of equation 1 is therefore not a diffusion resistance for there is also a convective transport of CO₂ through the shell of the casualty bag. This "resistance" is not just a property of materials of the bag, but also depends on the sublimation rate, as can be seen from Figure 4.

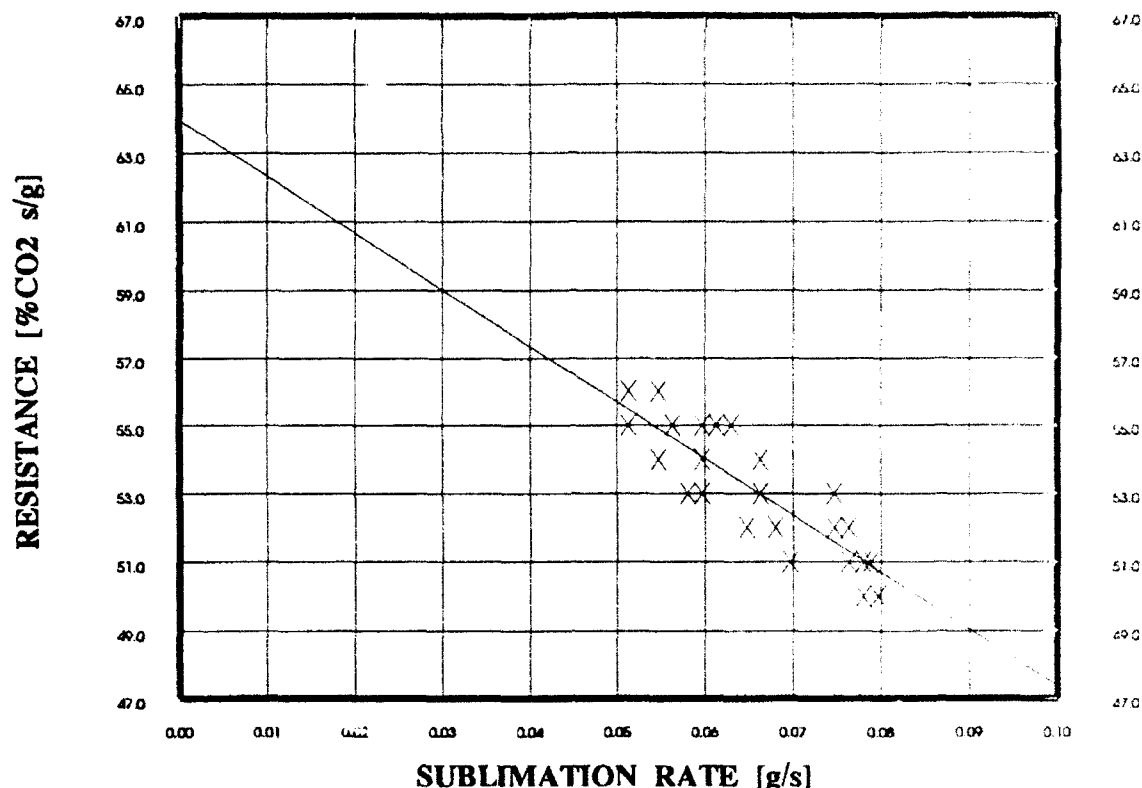


Figure 4. Resistance of the casualty bag to CO₂

The resistance during the steady state period was 51 [%CO₂]s/g. With this value, equation 2 can be used to estimate the steady state concentration of CO₂ that would have been reached had there been a human subject in the bag instead of a manikin.

$$C_{ss} = C_x + MxR \quad (2)$$

The CO₂ added to the airspace by respiration is small compared to that produced by the cooling device. The average resting man produces about 0.2 liters of CO₂ per minute (2) compared to over 2 litres per minute for the cooling unit. Because the human body has a very large capacity to absorb and store CO₂, it will take much longer to reach a steady state with a man in the bag. Equation 2 predicts a steady state concentration of 4.5 % CO₂. This level would be noticeable, for it would cause an uncomfortable increase in respiration rate. Levels of CO₂ up to 3% produce no discomfort in normal individuals. Respiration is increasingly stimulated by levels of 4, 5 and 6% CO₂. Still higher levels cause uncomfortably rapid breathing, i.e. gasping for breath, and a deterioration of mental competence (2). Although a concentration of 4.5 % is not toxic to normal, healthy individuals it might have a serious effect on a casualty. These cooling units should therefore normally be

vented to the outside, as recommended.

Because changes in sublimation rate occurred slowly compared to changes in concentration, for much of the time the bag was in a steady or quasi-steady state with respect to CO_2 . Therefore, the y-intercept of Figure 3, 64 [% CO_2] s/g, provides a rough estimate of the diffusion resistance of the bag. This value, and equation 2, can then be used to predict the steady state concentration of CO_2 that would result from just the respiration of a resting man. The result is about 0.5%, which would not be noticeable.

Two trials were carried out to measure the heat stress on a man in the casualty bag at a temperature of 35 °C and relative humidity of 15% (3). The CO_2 concentration in the air space was also measured. In one case, a steady state level of 0.5% was reached after approximately one hour, with occasional peaks as high as 1.1%. In the other experiment a steady state of 0.25% CO_2 was reached after three hours during which the concentration had varied erratically between 0.3 and 1.5%, but had averaged about 0.8%. Normal concentration of CO_2 in air is 0.04%.

In a hot climate, the evaporation rate of the dry ice would be higher and the operation time would be proportionately shorter. In the event of cooling unit leak, more CO_2 would be blown into the bag per unit time and the final steady state concentration of CO_2 in the casualty bag would be higher. At an air temperature of 50°C, the difference between dry ice temperature and air temperature would be 30% greater than in the experiment. The sublimation rate would therefore be 30% higher, at about 0.1 g/s. From Figure 3, the "resistance" at this higher sublimation rate should be approximately 47 [% CO_2] s/g. The total production of CO_2 , including the human portion, should be about 0.11 g/s. When these numbers are used in Equation 2, a steady state CO_2 concentration of 5.2% is predicted for the case of a total leak of the cooling unit exhaust into the bag at an air temperature of 50°C.

In the desert, evaporation can be so rapid that the skin might never actually feel wet even though the sweat rate is high. Clothing and the casualty bag impose a resistance to water vapour diffusion, and slow the rate of sweat evaporation. Sweat can then accumulate on the skin, and the clothing can become wet. If the skin becomes completely wet, it indicates that evaporation and heat-loss are at a maximum, which may not be adequate to balance the heat load without an increase in body temperature. This situation is bearable for only a short period (4).

In dry heat, the air in a bag that contains a sweating man will be cooler than the air outside because evaporation cools the skin which then cools the air enclosed by the bag. A normal soldier in a casualty bag at 45°C or 50°C would sweat profusely. A reduction in the heat-related distress of sweating subjects has been achieved by ventilating the casualty bag with low-humidity,

ambient temperature air. Although the air flow increased the airspace temperature, ventilation with air at 45 °C and 15% RH increased evaporation from the skin and doubled the tolerance time of the subjects used in the experiment (3). However, if the environment had also been humid, less of the sweat that was produced would have evaporated. Moreover, a casualty may not be able to sweat if severely dehydrated, burned or sunburned, or if he has been sweating profusely for a long period of time and his sweat glands are fatigued (5). Atropine will also cause anhydrosis. Without auxiliary cooling, a non-sweating, injured man will soon become a heat casualty.

At 50°C, the dry ice in the cooling unit would have a cooling power of about 65 watts, which is roughly equal to the heat produced by the body. However, this would not be enough, for even in the shade there would be an environmental heat load of at least this magnitude. Sweat would have to evaporate from the skin surface to remove the extra heat load. A cooling power of at least 130 watts will be required to avoid uncomfortable heat stress or the danger of heat stroke in the event that the casualty cannot evaporate sweat.

In refrigeration terms, this is a very small load. It is less than 10% of the capacity of an automobile air conditioner or a small residential window unit, and is comparable to the cooling capacity of a kitchen refrigerator. A rough estimate of the power required to drive a compressor to provide 130 watts of cooling can be obtained by applying the rule of thumb, of "one horsepower per ton of refrigeration" for an ideal system and multiplying by 1.5 to account for losses in a real system (6). A ton of refrigeration is equivalent to 3.5 kW and a horsepower to 0.75 kW. This suggests that a motor developing 1/20th H.P. or requiring an electrical input of about 40 watts would be required. This power level could be supplied by a small engine or motor-generator. Because of the mass of a compressor and a motor, the equipment is unlikely to be light in weight. A new development in refrigeration technology (7) might ultimately provide a lighter-weight solution applicable to many personnel cooling problems.

CONCLUSION

At room temperature, the dry ice in the personnel heater absorbed heat at an average rate of 46 watts for a period of an hour. Much of this cooling power would be wasted in cooling the environment, not the casualty. In a hot environment, the cooling unit should run at about 65 watts for three-quarters of an hour. This will not be enough to eliminate heat stress in a casualty, particularly if medication, dehydration, sweat gland fatigue or sunburn has compromised his ability to sweat or if high humidity minimizes evaporation. In hot weather, a casualty will need more cooling power than one HeatPac charged with dry ice can provide.

If one of these cooling units exhausts into the bag, the concentration of CO₂ should not greatly exceed 5%. This concentration is not toxic to normal individuals, but might be hazardous to an injured soldier. When the exhaust of the cooling unit is vented to the outside, the concentration of CO₂ in the bag should be about 0.5 %, which should cause no problems. Several of these units might be used at the same time to provide sufficient cooling but if more than one should leak into the airspace of the casualty bag, the concentration of CO₂ in the airspace could rise to a harmful level.

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A small, battery-powered fan heater charged with dry-ice was used in the air space of a casualty bag. The cooling power averaged less than 50 watts. In a hot environment, more than twice this cooling power is needed. When the carbon dioxide was allowed to leak into the airspace the concentration rose to a level that would be uncomfortable but not toxic.

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