

FAST-RESPONSE, WET-BULB THERMOCOUPLE

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ABSTRACT

The Bureau of Mines has developed a fast-response, wet-bulb thermocouple that is able to respond on a breath-by-breath basis to the changing inhalation and exhalation wet-bulb temperatures of a human subject while wearing a closed-circuit breathing apparatus. Bureau research has shown that wet-bulb temperature, taking into account both dry-bulb temperature and humidity, is the heat-

load stressor of importance to human subjects; therefore, the ability to measure this variable is considered important. Prior to this development, the ability to measure breath-by-breath wet-bulb temperature had not been achieved.

Introduction

The Bureau of Mines is investigating the impact of various levels of physiological stressors on human

subjects wearing respiratory protective devices. Such devices would be worn in underground coal mines for escape or rescue in the event that a fire or an explosion has made the atmosphere irrespirable. Typical physiological stressors include above ambient levels of CO₂, breathing resistance, temperature, and humidity. The Bureau is attempting to determine the human limits to these stressors beyond which physiological or mental performance is adversely affected. Adequate instrumentation was available for measuring gas concentrations, breathing pressures, and dry-bulb temperature but not wet-bulb temperature.

Description of Problem

Experience with hot and humid climates, as in Florida, versus hot and dry climates, as in New Mexico, demonstrates that it is not only the temperature of the air, but also the moisture content, that affects one's comfort and performance. It has been found in research sponsored by the Bureau (Gallagher, 1986) that the relevant measure of heat and humidity sensed by human subjects is the wet-bulb temperature. The wet tissues of the mouth and trachea function effectively as a wet-bulb thermometer. Wet-bulb temperature

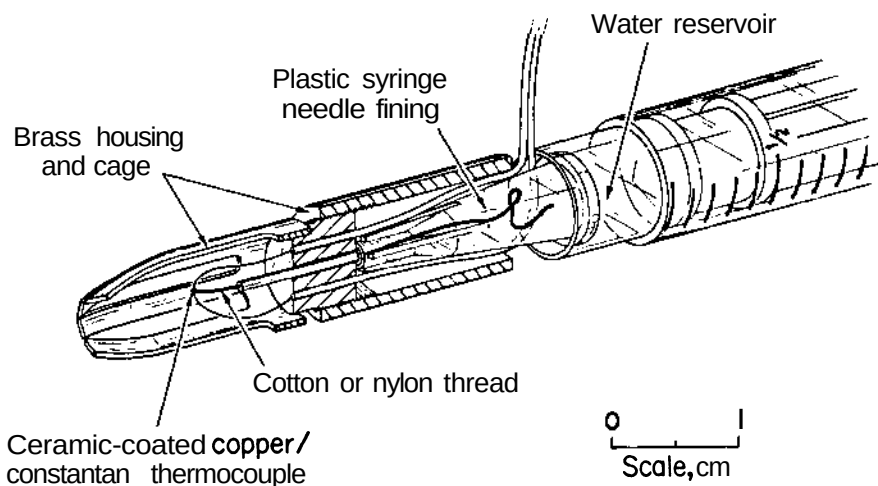


FIGURE 1

Schematic of the fast-response wet-bulb thermocouple.

takes into account both heat and moisture content. It is measured by covering the bulb of an ordinary thermometer with a wet cloth and flowing air past it at greater than some minimum flow rate. Just as a wet finger feels colder in the wind than a dry one, the wet-bulb thermometer will register a lower temperature than a dry-bulb thermometer. This is because the moisture is evaporating and absorbing heat from the finger and wet bulb in order to do so. If the air is already saturated with moisture, there is no evaporation nor a lowering of temperature of the finger. When wearing a breathing apparatus, if the air inhaled is hot but dry, the evaporation of moisture in the respiratory tissues makes it feel cooler.

The problem with using commercially available instruments to measure the wet-bulb temperature of the inhaled air of a breathing apparatus that has bidirectional flow is response time. Inhalations and exhalations occur at rates of around one each second. A sling psychrometer requires tens of seconds to respond. Other methods of measuring moisture con-

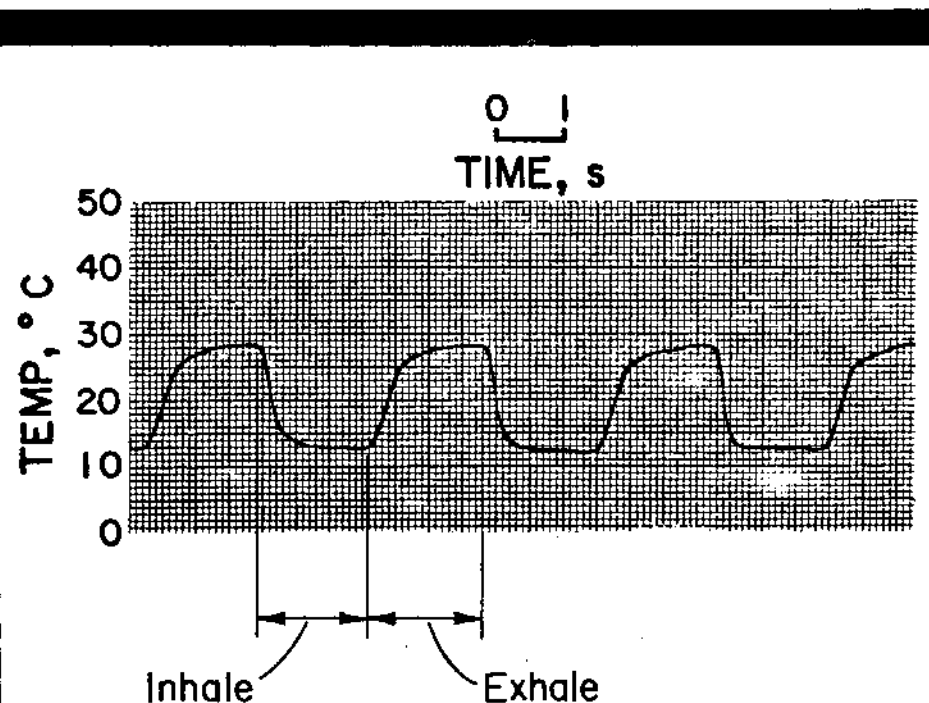


FIGURE 2

Inhale/exhale flow response of the thermocouple.

tent, such as dewpoint hygrometers, also suffer from this slow-response-time problem.

Solution

Reducing the mass of a thermo-

couple reduces the thermal inertia, thus reducing its response time. But covering a very small thermocouple bead with cloth, would be difficult. What was envisioned at that step was to dip a very small thermocouple in some sort of molten material that would solidify as a porous coating completely covering the thermocouple bead. After phone conversations with many humidity-measurement instrument companies across the country, a company was discovered that made just such a thermocouple. Decagon Devices of Pullman, WA manufactures a 1-mil, copper-constantan thermocouple, its bead coated with a porous ceramic material that acts to keep the thermocouple wet. At our request, Decagon reconfigured their product to that as shown in Figure 1. It consists of a metal tap with one end machined out to form a protective cage enclosing the thermocouple. This end is inserted into the air stream to be monitored. The metal cage pro-

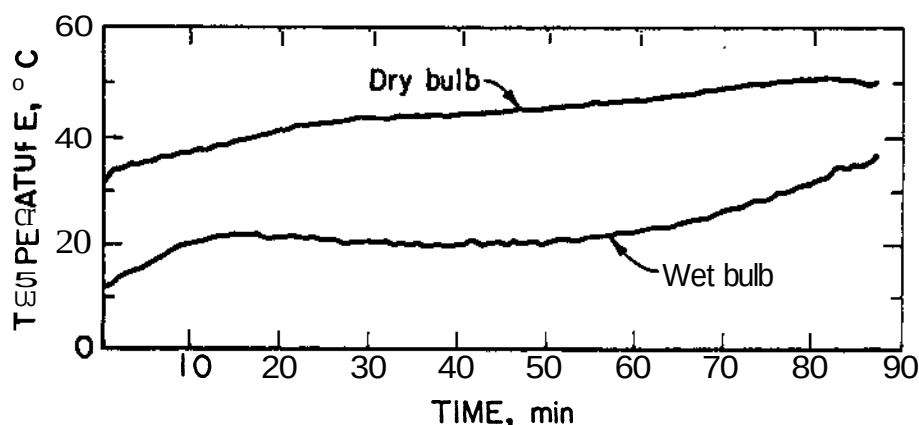


FIGURE 3

Wet-bulb versus dry-bulb temperature time chart of the inhaled air of a typical KO_2 closed-circuit breathing apparatus.

tests the delicate thermocouple but does not significantly occlude air flow in the hose of a breathing apparatus. A cotton or nylon thread, acting as a wick, touches the ceramic bead and extends to a small reservoir of water in the back of the tap. The time for 95% response is approximately 0.6 s. The response to inhale/exhale flow is shown in Figure 2.

Discussion

With this new tool, we can better evaluate closed-circuit breathing apparatus with regard to thermal burden to the user. As an example of the difference between the average wet-bulb and dry-bulb temperature of a typical KO_2 apparatus, see Figure 3. Compare this difference with that of a typical $LiOH/compressed-O_2$ apparatus, as in Figure 4. Both of these time charts were from tests performed on our automated breathing and metabolic simulator (Kyriazi, 1986). Even though the dry-bulb temperatures are similar for both of the ap-

parati, since KO_2 produces very dry O_2 , the KO_2 apparatus feels much cooler than the $LiOH/compressed-O_2$ apparatus.

The present U.S. standards for respiratory protective devices, as listed in 30 CFR 11, acknowledge the effect of moisture very crudely by having one set of dry-bulb temperature limits for those apparatus having inhaled air with 0-50% relative humidity (RH) and another set for those with 51-100% RH. Using wet-bulb temperature as the measure of heat load is preferable since one wet-bulb temperature implies an infinite number of combinations of dry-bulb temperatures and relative humidities. Otherwise, an apparatus with 10% RH is treated the same as one with 50% RH.

In the past, wet-bulb temperatures could not easily be measured on an apparatus with a bidirectional flowpath. With the development of this Fast-Response Wet-Bulb Thermocouple, this is now possible. Based on the recent

human physiological data as presented in reference 1, the Bureau recommends that WB temperature replace DB temperature as the measured parameter for inhaled gas and that the inhaled WB temperature be limited to less than or equal to $45^\circ C$.

Experience

The wet-bulb thermocouple functions as desired as long as the thermocouple remains wet. With an older design, keeping the bulb wet was a problem when monitoring KO_2 apparatus which produce very dry gas most of the test. At high temperature and low humidity, water was apparently evaporating at such a high rate from the thermocouple that the conveyance of water by the wick could not keep up, resulting in drying of the bulb and elevation of the temperature reading to dry-bulb. Keeping the wick exposure to the hot and dry air to a minimum by extending the wick sheathing out from the housing into the cage, reduces the likelihood of dry-outs.

References

1. Gallagher, S. and M. Vercruyssen (1986), "Interaction of Temperature and Humidity of Inspired Air on Tissue Temperatures if the Tongue and Hard Palate," JISRP. Vol. 4, Issue 2: 20-44.
2. Kyriazi, N. (1986), Development of an Automated Breathing and Metabolic Simulator. U.S. Bureau of Mines, Pittsburgh, PA Information Circular #9110.

