

54 Ventilatory responses and perceived respiratory effort of divers working at maximal physical capacity

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Respiratory problems facing the working diver are complex and include carbon dioxide retention, dyspnea, increased work of breathing and respiratory insufficiency. These problems can be compounded by inadequate design of breathing apparatus. The objective of this study was to evaluate proposed physiological acceptance criteria for underwater breathing apparatus, (Morrison and Reimers, 1982) by measuring the physiological responses of divers to a known work of breathing imposed by a selected breathing apparatus.

An underwater swimming ergometer was designed which allows divers to swim within the confines of a hyperbaric chamber. The ergometer allows work load to be increased by increments determined by a restraining force acting on the diver. Compressed air is supplied to the diver's breathing apparatus from two calibrated cylinders connected alternately by means of a four port, two position, valve. The cylinders are recharged at one minute intervals and ventilation is derived from a timed pressure drop within the supply cylinder.

Results obtained from unmanned testing of underwater breathing apparatus were used to select a breathing apparatus with characteristics which were closely representative of the recommended limit of work of breathing (Morrison and Reimers, 1982) at a depth of 50 metres. The performance of each diver was calibrated in terms of aerobic work ($\text{ml O}_2 + \text{kg}^{-1} \cdot \text{min}^{-1}$) per ergometric load (kg). Twelve divers performed graded exercise at depths of 0.5, 30 and 50 metres (seawater equivalent). Ergometric load was increased such that divers reached their aerobic capacity within 7 to 9 minutes. At each minute, the diver indicated perceived respiratory effort using a scale of 0 to 5 (where 2 = limit of comfort and 4 = limit of tolerance). Data were analysed to obtain ventilation, tidal volume, breathing frequency, heart rate, end tidal PCO_2 , 1st stage and 2nd stage (mouth) pressures at each depth.

In general divers could achieve their aerobic capacity at each depth. Perceived respiratory effort increased with both depth and workload, from "light" (score = 0.5) at moderate ventilations (33L/min) and 0.5 metres depth to "heavy" (score 3.25) at high ventilations (70L/min) and 50 metres depth. Divers were subject to hypoventilation and hypercapnia at 50 metres. At the highest workload attained by most divers, ventilations ranged from 61 to 84L/min at 50 metres compared with 81 to 120L/min at 0.5 metres for the same workload. The corresponding end tidal PCO_2 values were elevated to 48 to 62 mmHg at 50 metres compared with 33 to 40 mmHg at 0.5 metres.

55 Performance characteristics of open circuit demand regulators from 0.5 to 50 metres seawater

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A limiting factor in underwater work is the design and performance of breathing apparatus. In sport diving few manufacturers provide performance data. The objectives of this study were to measure work of breathing imposed by open circuit demand regulators and to compare regulator performance with recommended standards for underwater breathing apparatus.

A respiratory simulator was designed for unmanned testing of breathing apparatus in hyperbaric environments. The simulator operates inside a diving chamber, and is driven by a hydraulic pump and adjustable-frequency controller. Ventilation can be controlled at frequencies of 0 to 40 breaths/min and volumes of 1.0 to 3.5 litres. Volume and pressure measurements are transmitted via underwater connectors to a signal conditioning unit and micro-computer.

Seven open circuit demand regulators were selected from those currently in use in Canada. Each model was tested at a series of tidal volumes and respiratory frequencies to provide a ventilatory range of 15 to 75 L/min. Regulators were tested from 0.5 to 50 metres seawater depth. Ventilation and work of breathing relationships were

calculated at each depth. The work of breathing was partitioned into inspiratory and expiratory work, and both positive and negative (i.e. apparatus assisted) components of work were identified.

The performance of each open circuit demand regulator was compared with the recommended standards for underwater breathing apparatus of Morrison & Reimers (1) which have been adopted as guidelines by British and Norwegian authorities (2). Results indicated that only two of the seven models were capable of meeting proposed acceptance criteria in the range 0.5 to 50 metres and only one achieved the recommended ideal characteristics over the complete test range. In general, breakdown occurred at moderate to high levels of ventilation (40 - 75 L/min) and at depths in excess of 20 to 30 metres. In most cases breathing characteristics remained good up to the point of failure due to flow limitation at the demand regulator, when air supply became restricted and independent of additional breathing effort.

References

1. Morrison J.B. and S.D. Reimers, 1982. Design Principles of Underwater Breathing Apparatus. In: *The Physiology and Medicine of Diving*. Ed. P.B. Bennett and D.H. Elliott 3rd Ed. pp.55-98 Balliere Tindall, London.
2. Draft Guidelines for Minimum Performance Requirements and Standard Unmanned Test Procedures for Underwater Breathing Apparatus. Dept. Energy, U.K., and Norwegian Petroleum Directorate. Ref. OLJEDIRETURATET BN 82-7257 167- 6, 1984.

56 Prediction of moisture permeability of clothing worn

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Now that moisture permeation of clothing worn has received extensive studies (Woodcock, 1962; Nishi and Gagge, 1970; Goldman, 1974), prediction models seem to have been satisfactory for a practical use. Nevertheless, significance of porosity of fabric and clothing design has been insufficiently discussed to date. The present study deals with these essential factors for further improvement of the prediction models.

1) Porosity as related to moisture permeability

Mekjavic *et al.* (1986) observed the rate of gas (N_2) exchange through fabric, demonstrating that moisture permeability correlated linearly with air breathability. Using the same method, a curvilinear relationship between air breathability and porosity was then found. Thus, porosity is directly related to moisture permeability of fabric.

2) Clothing design as related to clothing microenvironment

Any attempt to extrapolate thermal characteristics of clothing worn from those of fabric used would likely involve inherent problems which are due largely to the difficulty of estimating clothing design such as clothing fit, area (A_{cl}) covered by clothing worn and the number of openings. In support of finding solution, however, these functions may be incorporated in clothing microenvironment (V_{μ}) and ventilation index (VI) in one way or another. For example, the average thickness of clothing microenvironment can be simply derived by dividing V_{μ} by A_{cl} . Thus, V_{μ} and VI are certainly related to clothing design.

3) Prediction of moisture permeability of clothing worn

Based on the prediction equation proposed by Kakitsuba *et al.* (1981), a new prediction equation for moisture permeability of clothing has been proposed:

$$E_{sk}/(h_{ea} \cdot \Delta P_v) = \frac{\%}{\{1 + h_{ea} \%/h_{e\mu} + 1/h_{ecl}\}} \quad (1)$$

where, E_{sk} = the rate of evaporation from the skin ($Kcal/m^2 \cdot hr$), h_e = the evaporative heat transfer coefficient ($kcal/m^2 \cdot hr \cdot torr$, a = ambient air; μ = microenvironment; cl = clothing layer), $\%$ = porosity (N.D., $0 \leq \% \leq 1$) and ΔP_v = vapor pressure difference