

NOTE

A multicalorimeter for the study of biological activity in marine sediments

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ABSTRACT: A multicalorimeter is described which allows the measurement of heat production of up to 10 sediment samples simultaneously. System regulation as well as data processing and evaluation are performed by personal computer. The instrument performs well even at non-controlled room temperature down to -0.5°C on board a research vessel. First results from tests employing pressure chambers are presented. An example for a deep-sea heat-production profile is given from the Norwegian Basin, depicting subsurface maxima in benthic activity.

Direct microcalorimetry has been widely used in biological sciences (Wadsö 1975, Ljungholm et al. 1980, Gnaiger 1983, Lock & Ford 1985). In biological oceanography the technique has been used for the investigation of anaerobic metabolism of benthic invertebrates (Pamatmat 1978, Famme & Knudsen 1983, Shick 1981, Hammen 1983) and of soft bottom community metabolism (Pamatmat 1982). The method measures simultaneously all types of metabolism in a community; thus the rate of heat loss is enthalpy change and the last step of energy flow through the system. The combustion value of metabolized organic matter is equivalent to the released heat.

The method has been used to calculate carbon budgets (Graf et al. 1982, 1983). Recently, the reliability of these budgets was demonstrated by direct calorimetry of a predominantly anaerobic sediment (Graf 1987). By comparison, oxygen consumption, also called indirect calorimetry, only accounted for the top-most few millimeters of sediment activity and greatly underestimated the amount of metabolized organic matter in the lower layers.

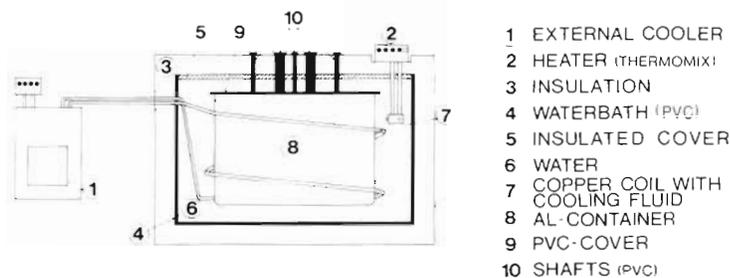
Most calorimeters used are of the heat conduction type. These work isothermally and need long equilibration times (Calvet 1956), making direct calorimetry

a relatively slow method. To overcome this problem, it is desirable to increase the number of devices in use simultaneously. An example is given by the Pamatmat double twin calorimeter (Pamatmat 1978). In the present article we present a multicalorimeter which can measure 10 samples simultaneously, thus enabling the measurement of a sediment heat flow profile in one run. Other features of the instrument for calorimetry of sediments have been improved. The multicalorimeter works at low temperature on board ship and accommodates larger samples than commercially available instruments. Furthermore the chambers can be compressed to simulate in situ pressure up to 310 bar.

Description of the instrument. The calorimeter block is placed inside a PVC-covered aluminium container (90 cm diameter) and fixed inside a well-insulated constant-temperature bath (Fig. 1). The aluminium container is completely submersed except for PVC shafts through which samples are inserted into the instrument. Temperature is regulated by an external cooler (Braun, Frigomix 1497 and Thermomix 1480E), which is connected to a copper coil surrounding the container, and an internal heater (Braun Thermomix, 1480E), creating an accuracy of $\pm 0.005^{\circ}\text{C}$. A mixer increases turbulence in the water bath. It is possible to run the instrument at -0.5°C at unregulated ambient room temperature.

The calorimeter block is constructed from about 200 kg of aluminium and has the shape of a 10-armed star (Fig. 2). Fig. 3 shows 2 sections of this construction. The left side depicts a tangential section through 2 arms including the PVC shaft for sample insertion and removal (8). The left arm holds a V4A-steel chamber (6 cm external diameter) containing the sediment sam-

Fig. 1. Temperature-regulating scheme of the multicalorimeter. External cooler (1) and internal heater (2) keep the calorimeter at constant temperature. Samples are introduced via the shafts (10)



ple while the right arm is empty. Chambers of varying heights can be accepted by rising or lowering an aluminium piston (4) from above via a fishing line. Maximum chamber height is 4 cm, allowing a maximum sample size of about 70 cm³.

Since the calorimeter is run isothermically, the heat produced inside the steel chamber creates a temperature gradient from the sample towards the surrounding

aluminium block (heat sink) (Fig. 3: 5) and thus a heat flow. This flow passes Peltier elements or thermopiles (Fig. 3: 3) (CP 1.4-71-10L, supplied by Walz, Effeltrich), which generate an electric current. The 2 Peltier elements contacting the chamber are connected in series, thus integrating the total heat flow from the steel chamber. In order to obtain a stabilized signal the Peltier elements are connected in series opposite to an identical set of Peltier elements in a compensation chamber located at the center of the calorimeter block. Fig. 3 (right side) shows a radial section of one arm including the central compensation chamber. This part of the multicalorimeter represents a twin calorimeter (Wadsö 1975).

MULTICALORIMETER MEASURING AND EVALUATION SCHEME

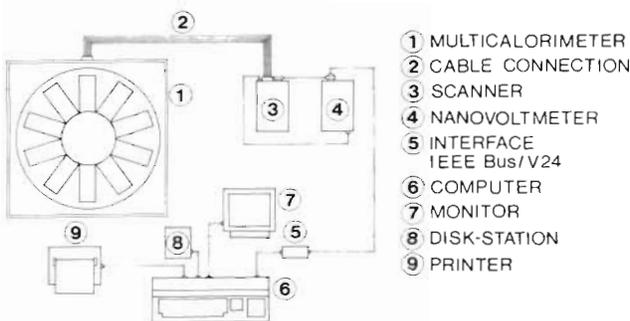


Fig. 2. Measuring and evaluation scheme of the multicalorimeter

Measuring and evaluation design. The thermopile voltage is measured by a micro- or nanovoltmeter (Keithley 195A or 181) (Fig. 2). A scanner (Keithley 705), controlled by a computer (Atari 520 ST+) switches successively from one arm to the next, always keeping the central chamber for compensation. Every 20 min each sample is measured for 2 min. Because sediment thermograms change only slowly (Pamatmat 1983), continuous monitoring of the heat flow is not

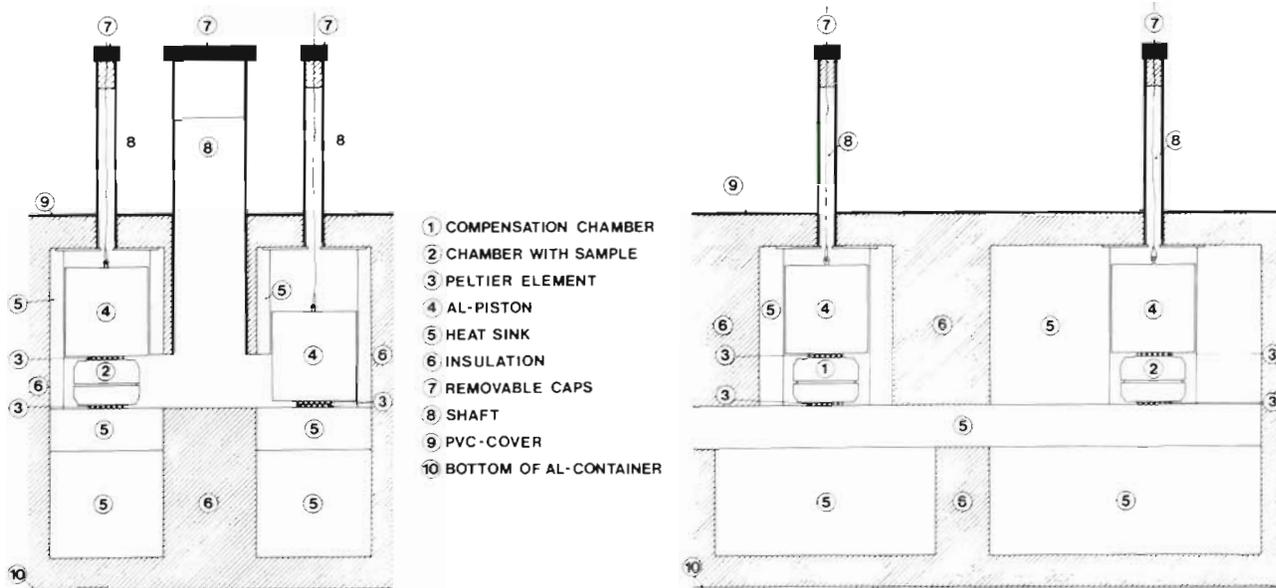


Fig. 3. *Left*: Tangential, and *right*: radial section through the calorimeter block. Chamber diameter is 6 cm. Cable connections are not depicted

necessary. During a run thermograms of each chamber can be viewed on the monitor. Final evaluation, i.e. integration of the thermogram and correction for baselines, is done by the computer. All programs are written in 'C' language. More details on the software are given by Altenbach & Weinholz (1987). The calorimeter is calibrated by passing a current of 1 to 3 mA through a 50 Ω resistor placed inside the steel chambers (cf. Berger 1969). Differences in the Peltier elements create different calibration factors for the 10 arms of between 1.50 and $2.05 \times 10^{-5} \text{ W } \mu\text{V}^{-1}$ and a standard deviation of one device of $\pm 1\%$. Baseline drift is less than $1 \mu\text{V d}^{-1}$ and can be monitored in one arm.

A critical aspect in the design of a multicalorimeter is avoidance of interactions between different heat flows from adjacent chambers. During a normal calibration run in one arm of the instrument there was no detectable signal in the other arms. Only if calibration heat was raised to a factor 1000 above sediment heat production was an effect of less than 1% visible, indicating that the heat sink is sufficient.

Case study. During 'Meteor' Cruise M/2 to the Norwegian Sea the multicalorimeter was tested on board and run at -0.5°C . Fig. 4 depicts the heat production of a sample from a deep-sea station in the Norwegian Basin (M/59; $65^\circ 31.0' \text{ N}$, $00^\circ 07.1' \text{ W}$) at 3062 m water depth using non-compressed chambers. A strong gradient is visible in the top 3 cm of the sediment, with 2 maxima in deeper sediment layers. These subsurface maxima were detected frequently during this expedition and will be discussed elsewhere. The absolute values, however, are comparable to shallow-water measurements (Graf et al. 1983). In comparison with a carbon supply of a few grams $\text{m}^{-2} \text{ yr}^{-1}$ expected for this area the measured heatflow seems too high. One explanation is increased metabolic rate from decompression. At Station M/78 ($70^\circ 00.4' \text{ N}$, $00^\circ 04.1' \text{ W}$) at 3294 m water depth 2 special steel chambers with 10 mm thick walls were tested. The

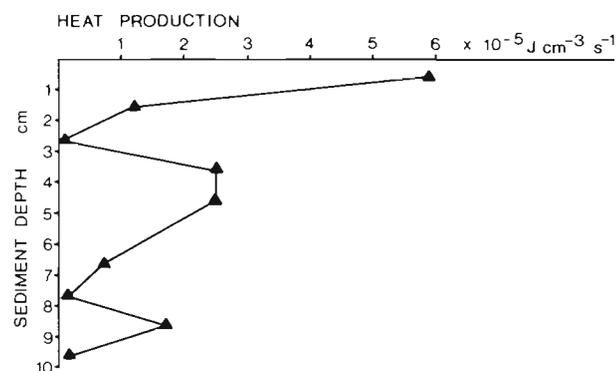


Fig. 4. Heat production profile of a deep-sea sediment from the Norwegian Basin

chambers were connected to an HPLC pump and compressed to 310 bar with water overlying the sediment. Heat release of the sediment (0 to 2 cm) decreased from 2.83 to $0.59 \times 10^{-5} \text{ J cm}^{-3} \text{ s}^{-1}$, a factor of 5 smaller. In the 2 to 4 cm layer the effect was less pronounced, decreasing from 1.30 to $0.77 \times 10^{-5} \text{ J cm}^{-3} \text{ s}^{-1}$. The values given in Fig. 4 thus give only decompressed heat production rates.

The instrument can measure heat flow of deep-sea samples at in situ pressure, but it remains to be seen if such rates are completely reversible after decompression.

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