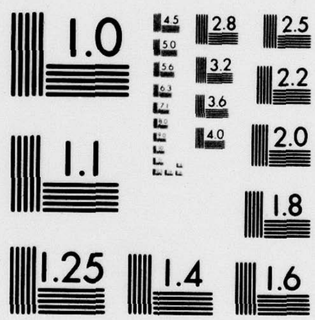
AD-A076 260 BATTELLE MEMORIAL INST COLUMBUS OHIO COLUMBUS LABS F/G 6/11
DEVELOPMENT OF AN EXPERIMENTAL BREATHING GAS HEATER TO SUPERVIS--ETC(U)
SEP 69 P S RIEGEL , G H ALEXANDER N00014-66-C-0199

UNCLASSIFIED NL

| OF |

AD
A076260

END
DATE
FILMED
11-79
DDC

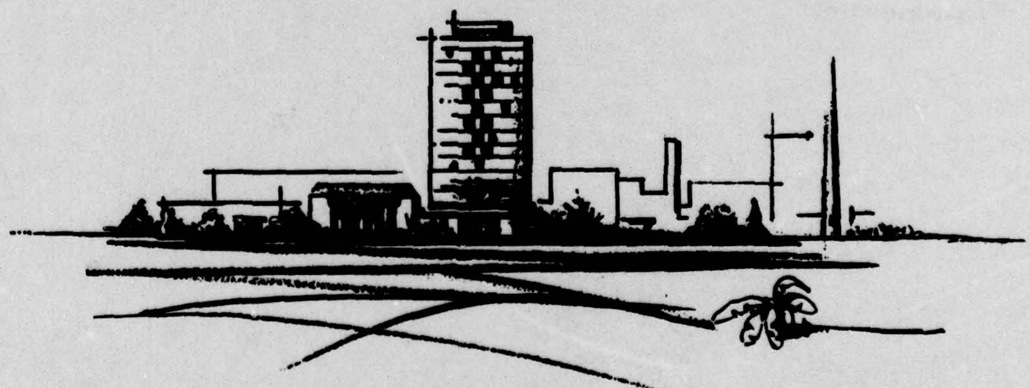

1.0
4.5
5.0
5.6
6.3
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

DF ___ "RETURN 485
HAC ✓ (00649)

LEVEL II

SC

RESEARCH REPORT



APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

BATTELLE MEMORIAL INSTITUTE

COLUMBUS LABORATORIES

79 11 06 066

79 05 02 046

THE COLUMBUS LABORATORIES of Battelle Memorial Institute comprise the original research center of an international organization devoted to research.

The Institute is frequently described as a "bridge" between science and industry – a role it has performed in more than 90 countries. As an independent research institute, it conducts research encompassing virtually all facets of science and its application. It also undertakes programs in fundamental research and education.

Battelle-Columbus – with its staff of 3,000 – serves industry and government through *contract research. It pursues:*

- research embracing the physical and life sciences, engineering, and selected social sciences
- *design and development of materials, products, processes, and systems*
- information analysis, socioeconomic and technical economic studies, and management planning research.

505 KING AVENUE • COLUMBUS, OHIO 43201

(1)

TASK REPORT

on

9 Research rept.,

6

DEVELOPMENT OF AN EXPERIMENTAL
BREATHING GAS HEATER

to

SUPERVISOR OF DIVING
UNITED STATES NAVY,

[redacted] N00014-66-C-0199

15

September 24, 1969

11 24 Sep 69

by

10 P. S. Riegel, G. H. Alexander, J. S. Glasgow, [redacted] D. W. Frink

12 79

BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

401 817

Battelle Memorial Institute · COLUMBUS LABORATORIES

505 KING AVENUE COLUMBUS, OHIO 43201 · AREA CODE 614, TELEPHONE 299-3151 · CABLE ADDRESS: BATMIN

September 24, 1969

Captain E. B. Mitchell
United States Navy
Supervisor of Diving
Naval Ships Systems Command
Code OOC
Main Navy Building, Room 3023
Washington, D. C. 20360

Dear Captain Mitchell:

Task Report
on
Development of an Experimental
Breathing Gas Heater

Contract No. N00014-66-C-0199

Enclosed are three copies of the Task Report on "Development of an Experimental Breathing Gas Heater".

The prototype heater was built and delivered in time for use in the 600-foot saturation dive at Duke University in June, 1969. After some modification it performed its intended function.

The heater should serve in the lab and on future dives as a useful research tool for evaluating human respiratory heating requirements, and lead to the development of more sophisticated generations of heaters.

Should you have any questions or comments concerning the contents of this report, please call us.

Sincerely,

Peter S. Riegel

P. S. Riegel
Research Engineer
Equipment Engineering Research Division

PSR/jbs
Enc. (3)

cc: LCdr. W. I. Milwee, Jr.
Mr. Denzil Pauli
Lt. Harry Cole
LCdr. Herman S. Kunz

TASK REPORT

on

DEVELOPMENT OF AN EXPERIMENTAL BREATHING GAS HEATER

to

SUPERVISOR OF DIVING
UNITED STATES NAVY

from

BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories

September 24, 1969

INTRODUCTION

One of the basic problems in diving has been that of keeping the diver warm in cold water: wet suits, dry suits, and heated suits have provided thermal protection and heat. However well protected the diver may be by these garments, it is only in recent years that depths have been attained which make necessary the consideration of respiratory heat losses. Each time a person breathes, the inhaled gas is heated to body temperature and exhaled, which results in heat loss. Under surface conditions, this presents no problem, since the mass of gas respired, and hence the exhaled heat content, is not large. However, as depth increases, the mass of respired gas increases until, at extreme depths, the heat loss by exhalation becomes excessive. To better define the problem of respiratory heat loss, the Experimental Diving Unit of the U. S. Navy asked Battelle to develope and construct a prototype heater that would allow research to be conducted with human subjects.

SUMMARY OF RESEARCH ACTIVITY

In June, 1969, a breathing-gas heater was successfully designed and built for the 600-foot dives by the Experimental Diving Unit in hyperbaric facilities at Duke University. Events leading to this successful development began on April 9, 1969, in a progress review meeting, at which it was decided that a breathing-gas heater would be needed for the Duke dive by June 1, 1969. A task description was written to define the scope of the task, and preliminary calculations of the heat requirements were begun. Approval of the task description was given at the Project Review Meeting on April 29, 1969. Again, delivery time was specified as June 1, 1969, which allowed about a month for calculation, design, construction, testing, and delivery of the unit.

Because of the short lead time, design and construction occurred concurrently. Accordingly, the size of the breathing-gas heater was arbitrarily determined from what was felt to be the maximum size that could comfortably be borne by a diver. Hot water was selected as the heat source because of the low potential hazard and because hot water would be available from the Welson suit to be worn by the diver.

Originally, it was intended that the heater would be worn on the diver's chest and that the heated gas would take a very short path from the heater to the diver's mouthpiece. However, because of space requirements, the heater was attached to the right side of the diver's waist and a 30-inch-long corrugated hose was used to transmit the heated gas to the diver's mouthpiece. Because of the excessive length of this hose the gas, although warm when it left the heater, cooled by the time it got to the diver, and operation of the heater was unsuccessful.

The heater was returned to Battelle and the 30-inch hose was removed. A new hose, wrapped with a spiral of Tygon tubing, was attached. The hot-water discharge from the heater was routed into the Tygon tubing and thus the gas temperature could be maintained from the point where it left the heater to the diver's mouthpiece. The heater as used on the Duke dive is shown in Figure 1. Because of instrumentation problems, it was not possible to get a temperature reading at the diver's mouthpiece on the Duke dive; however, the diver's comment was that the gas was warm.

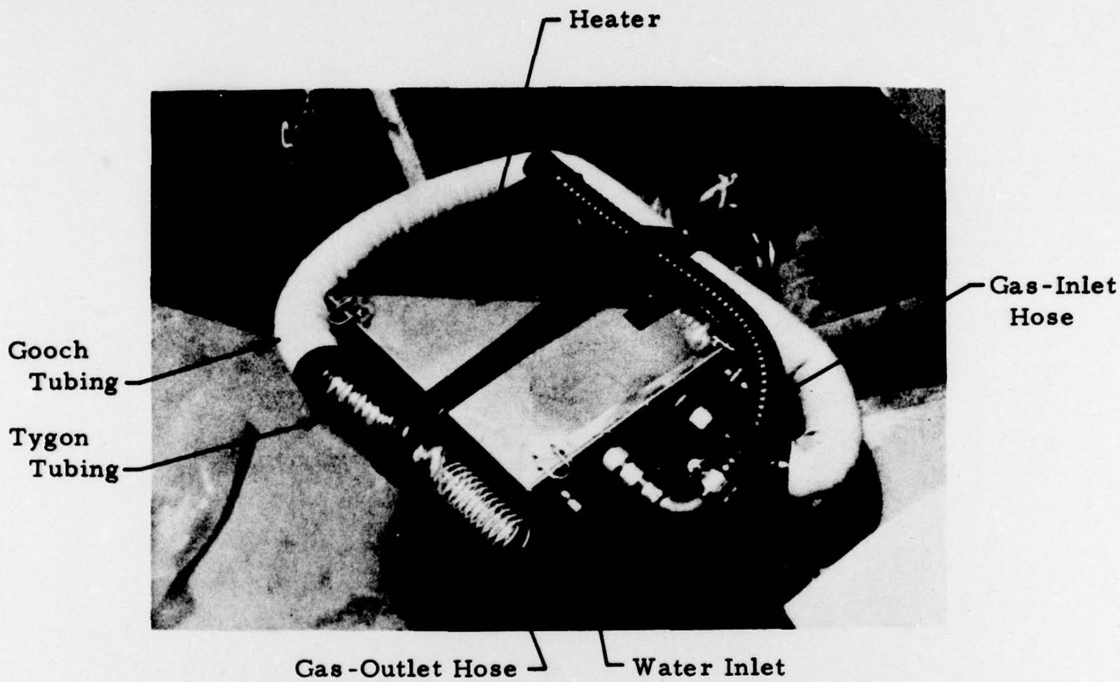


FIGURE 1. HEATER AS USED ON DUKE DIVE, JUNE, 1969

CONCLUSIONS

Both laboratory testing and field evaluation in a 600-foot saturation dive have shown that the breathing gas is effectively heated by the prototype device. However, the losses between the heater outlet and the diver are too great. To be truly effective, heat must be conserved from the time it leaves the heater until it enters the diver's respiratory passages. Thus, losses between the heater and the diver must be minimized.

The breathing-gas heater is an effective tool for heating the breath of a diver under controlled research conditions. It can be used for human-subject research on subsequent chamber dives and will pave the way for the development of more compact, sophisticated units once the heating requirements of respiration are established by use of the prototype heater on further hyperbaric experiments.

DESCRIPTION OF HEATER

The prototype heater is rectangular, with overall dimensions of approximately 2 x 10 x 10 inches. It is shown schematically in Figure 2, assembled in Figure 3, and disassembled in Figures 4 and 5. It has four fluid connections, two water and two gas. Because the heater is symmetrical, some confusion can occur about which tube is the gas inlet and which is the outlet, although they were labeled before shipment. The outlet is brazed around the base of the tube on the heater cover, the inlet is not. The spined heat-transfer tubes can be seen through the outlet; only a flat metal surface can be seen through the inlet. The water travels along two parallel paths of nine spined tubes each*, for a total of 18 tubes. The jacket of the heater is stainless steel, and the water passages are copper. Heater surfaces are insulated from the surrounding water by the incoming gas, which passes around the internal heating elements, then rises through them and emerges at the top.

TESTING

It was initially proposed that hyperbaric tests would be made on the prototype. This was found to be unnecessary because use of the heat-exchanger-effectiveness ratio permits accurate predictions of hyperbaric performance based on the results of flow tests made under atmospheric conditions. Effectiveness ratio compares actual heat-transfer rate in a given heat exchanger to the rate that would be obtained in a counter-flow heat exchanger having infinite heat-transfer area.

---

*Heatron Thermek tubes, 1/8-inch SPS, 7/8-inch O.D., copper, as manufactured by Heatron Inc., York, Pennsylvania.

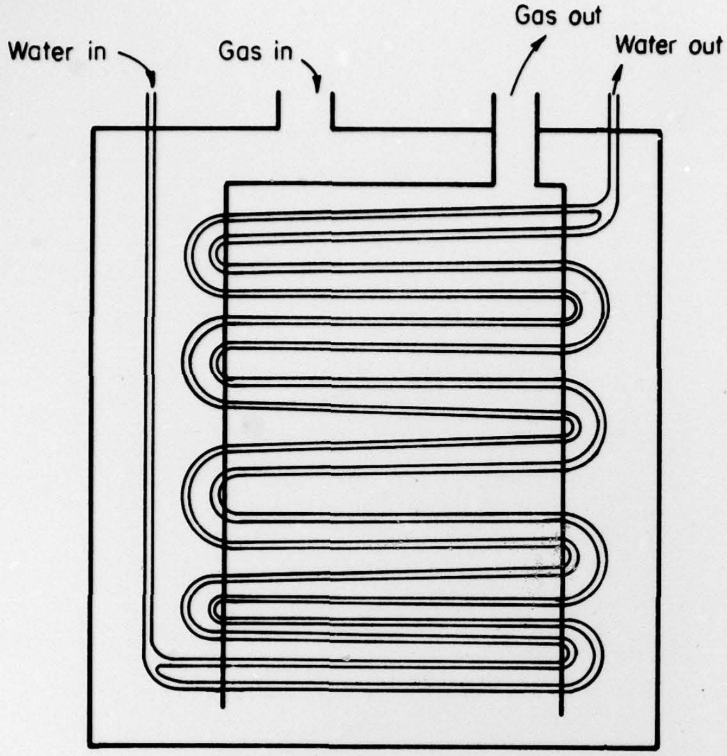
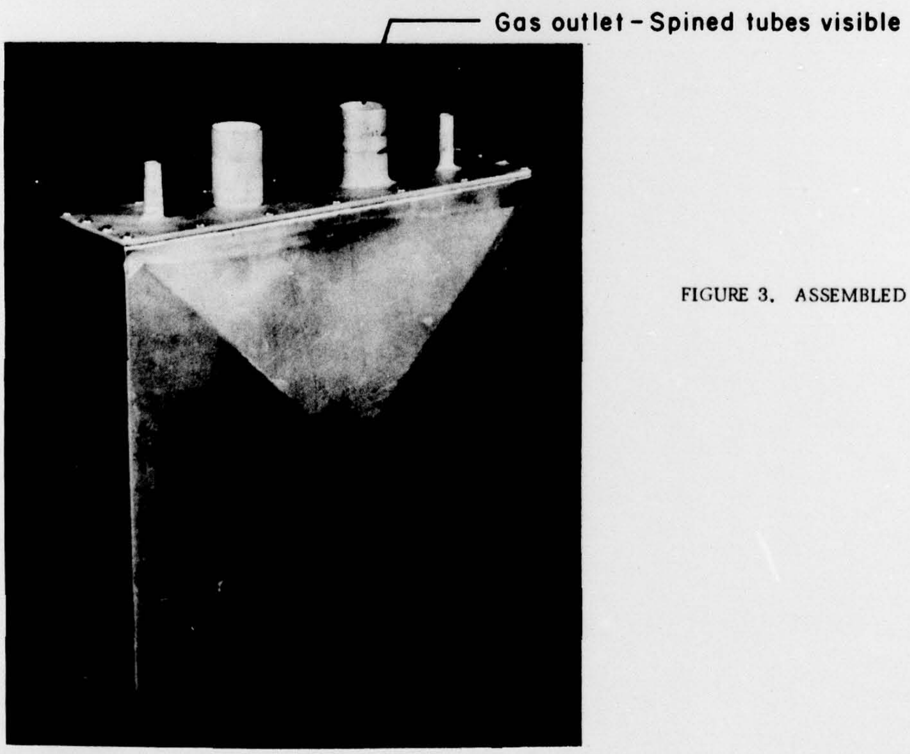


FIGURE 2. HEATER SCHEMATIC



C6709

FIGURE 3. ASSEMBLED HEATER

TASK REPORT

on

DEVELOPMENT OF AN EXPERIMENTAL BREATHING GAS HEATER

to

SUPERVISOR OF DIVING
UNITED STATES NAVY

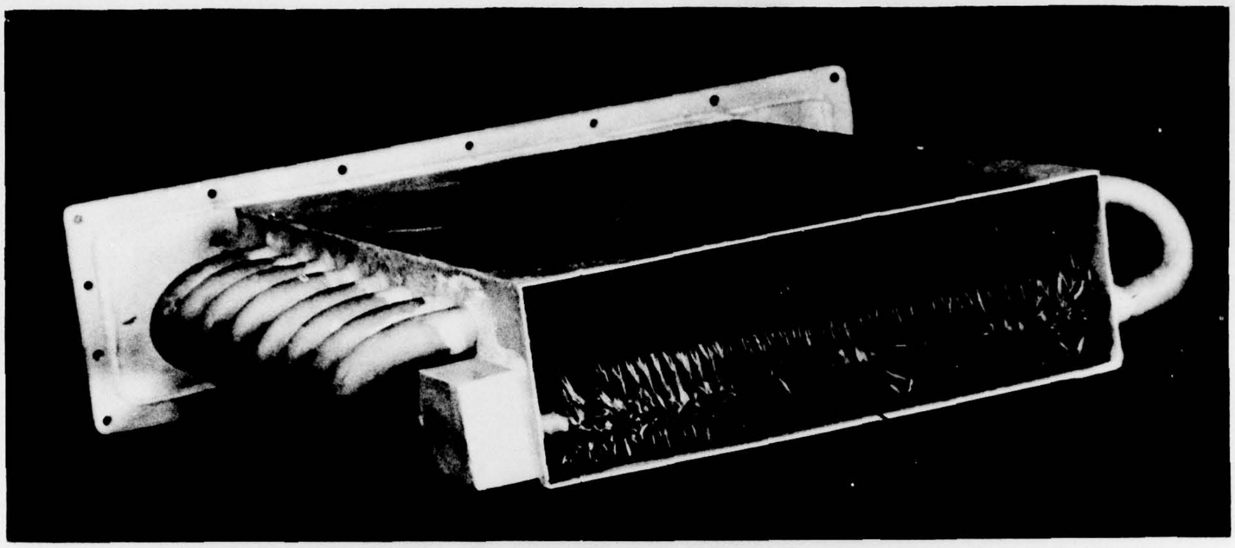
Contract No. N00014-66-C-0199

September 24, 1969

by

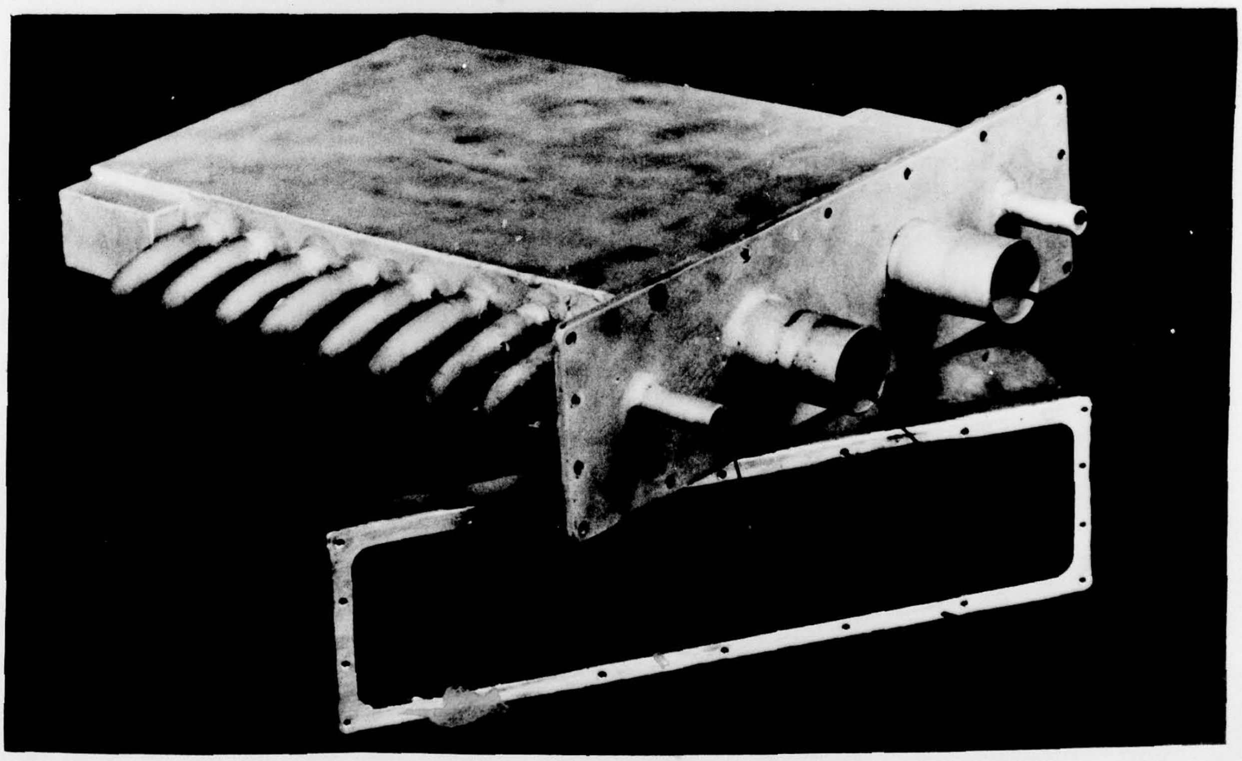
P. S. Riegel, G. H. Alexander, J. S. Glasgow, and D. W. Frink

BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201



C6707

FIGURE 4. HEATER DISASSEMBLED



C6708

FIGURE 5. HEATER DISASSEMBLED

An air test was run at room temperature (72 F) to establish one set of operating conditions, which was all that was necessary to determine the effectiveness ratio. It was found that, at a flow of 10 cfm of air entering at 38 F and a flow of 5.3 lb/min of water entering at 131 F, the exiting air would be heated to 128 F and the water temperature would drop to 128 F. No difference in performance was noted when the entire heater was immersed in ice water. Thus, it was concluded that insulation was unnecessary.

Two pressure tests were conducted on the water tubing. No leakage occurred when the tubes were pressurized with 20 psig helium and held at pressure. A water pressure test was also conducted, and it was found that the unit could safely sustain 50 psig water pressure, which is more than adequate for the application. Gas passages showed no leakage during the course of the test program when the heater was immersed in water; the interior stayed dry throughout testing.

PERFORMANCE PREDICTION AND EVALUATION

Performance of the breathing-gas heater was established in three parts: (1) a preliminary estimate based on manufacturers' data, (2) a flow test to determine operation at one flow condition, and (3) an accurate analysis of heater capabilities based on actual performance data.

Performance evaluation followed this order: (1) calculation of worst-case conditions of temperature, gas mix, and flow, (2) preliminary calculation of heat required, (3) preliminary design of prototype heater, (4) calculation of overall heat-transfer coefficient based on tube-manufacturers' data, (5) prediction of effectiveness ratio based on tube-manufacturers' data, (6) prediction of gas-outlet temperature, (7) construction and testing of prototype, (8) effectiveness-ratio calculation based on actual performance data, (9) calculation of overall heat-transfer coefficient based on test data, and (10) effectiveness-ratio calculation and prediction of performance under proposed operating conditions.

The calculations based on tests showed that the heater, for a respiratory minute volume of 1 cfm, will provide gas at temperatures ranging from 82 F at peak inhalation rate to 115 F at no flow, when supplied with a water flow of 5.4 lb/min at 115 F, at 1000 ft depth.

Calculations are included as an appendix to this report.

ACKNOWLEDGMENT

We wish to acknowledge the assistance of Captain E. B. Mitchell, Supervisor of Diving and LCdr W. I. Milwee, Jr., Project Officer, Experimental Diving Unit, United States Navy, for their assistance throughout the research program.

REFERENCES

(1) "Respiratory Heat Loss With High Density Gas Mixtures" by Paul Webb and James F. Annis, May 31, 1966. Final Report on Contract Nonr 4965(00). Sponsored by Office of Naval Research, Department of the Navy, Washington, D. C. 20360.

(2) Elements of Heat Transfer by M. Jakob and G. A. Hawkins. Third Edition, John Wiley and Sons, New York, April, 1958.

(3) Compact Heat Exchangers by W. M. Kays and A. L. London, The National Press, Palo Alto, California, 1955.

(4) "Heat Transfer Through Metallic Walls", Bulletin A-348. The International Nickel Co., New York.

(5) Heatron Thermek Brochure.

APPENDIX

HEAT TRANSFER CALCULATIONS

CALCULATIONS

Worst-Case Gas Mix and Flow

Mix

$$\text{Maximum Depth} = 1000 \text{ ft}$$

$$\text{Maximum } PO_2 = 1 \text{ ATA (assumed)}$$

$$\text{Percent } O_2 = \frac{PO_2\ (3300)}{\text{Depth} + 33} = \frac{(1)\ (3300)}{1000 + 33} = 3.2 \text{ percent} \quad .$$

Flow

$$\text{Design flow at 1000 ft} = 1 \text{ cfm}$$

$$\text{Surface flow} = \text{depth flow} \times \frac{(\text{depth} + 33)}{33}$$

$$= 1 \times \frac{1033}{33} = 31.3 \text{ ft}^3/\text{min}$$

Heat Required

$$q = [\,mc\,]_{mix}\, T = [\,(mc)_{O_2} + (mc)_{He}\,]\ T \quad ,$$

where

m = mass flow rate, lb/hr

c = specific heat, B/lb-F

T = temperature rise, F

q = heat required, B/hr.

$$q = \left[\left(\frac{31.3 \text{ ft}^3 \text{ mix}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{.0827 \text{ lb}}{\text{ft}^3\ O_2} \times \frac{3.2 \text{ ft}^3\ O_2}{100 \text{ ft}^3 \text{ mix}}\right)\left(.217\ \frac{\text{B}}{\text{lb-F}}\right)\right.$$

$$\left. + \left(\frac{31.3 \text{ ft}^3 \text{ mix}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{.0103 \text{ lb}}{\text{ft}^3 \text{ He}} \times \frac{96.8 \text{ ft}^3 \text{ He}}{100 \text{ ft}^3 \text{ mix}}\right)\left(1.25 \text{ B/lb-F}\right)\right] \ (95 \text{ F} - 32 \text{ F})$$

$$= (mc)_{mix}\ T$$

$$= \frac{24.4 \text{ B}}{\text{hr-F}} \times 63 \text{ F} = 1530 \text{ B/hr} \quad .$$

Overall Heat-Transfer Coefficient (UA)

$$UA = A/\left(\frac{1}{h_1} + \frac{X}{K} + \frac{1}{h_2} + \text{fouling factor}\right) \quad ,$$

where

h_1 = inside film coefficient, $B/hr\text{-}ft^2\text{-}F$

h_2 = outside film coefficient, $B/hr\text{-}ft^2\text{-}F$

X = thickness, ft

K = thermal conductivity $B/hr\text{-}ft\text{-}F$

A = outside area of tubes, ft^2.

From the Thermek brochure,

$h_1 = 530$

$\frac{X}{K} = 1.53 \times 10^{-5}$

$h_2 = 5$ to 20

fouling factor = .002.

Also, for 18 tubes, each 5-3/8" long, $A = 3.2\ ft^2$,

substitution yields the following:

$$16 < UA < 64\ B/hr\text{-}F \quad .$$

Heat Exchanger Effectiveness Ratio (E)

For a counterflow heat exchanger operating in the flow ranges under consideration,

$$E = 1 - e^{-\frac{UA}{mc}} \qquad (1)$$

both UA and mc have been previously determined, and substitution yields:

$$\text{for } UA = 16,\ E = 1 - e^{-\frac{16}{24.4}} = .48$$

$$\text{for } UA = 64,\ E = 1 - e^{-\frac{64}{24.4}} = .93 \quad .$$

Gas-Outlet Temperature

$$E = \frac{t_2 - t_1}{t_3 - t_1} \tag{2}$$

where

E = heat exchanger effectiveness ratio

t_1 = temperature of entering gas, F

t_2 = temperature of exiting gas, F

t_3 = temperature of entering water, F

for the design conditions,

$t_1 = 32$

$t_3 = 115$

E = between .48 and .93

substitution yields

t_2 max = 109 F

t_2 min = 72 F .

These gas-outlet temperatures defined an acceptable range, and no reason was seen to modify the prototype design.

Test of Prototype

Once the construction of the prototype heater was complete, it was tested using air at atmospheric pressure as the flow medium. Effectiveness of a heat exchanger may be accurately predicted for varying conditions if the four temperatures and two flows are known for one condition. The performance characteristics were determined by measuring flows and temperatures as follows:

t gas in = 38 F = t_1

t gas out = 128 F = t_2

gas flow = 10 cfm = . 47.7 lb/hr

t water in = 131 F = t_3

t water out = 128 F = t_4

water flow = 5.4 lb/min

Actual Heat-Exchanger Effectiveness Ratio

$$E = \frac{t_2 - t_1}{t_3 - t_1} = \frac{128 - 38}{131 - 38} = 0.968 .$$

Calculation of Actual Overall Heat-Transfer Coefficient

$$E = 1 - e^{-\frac{UA}{mc}}$$

$$mc = 47.7 \text{ lb/hr} \times 0.24 \text{ B/lb-F} = \frac{11.4 \text{ B}}{\text{hr-F}} .$$

substitution yields

$$0.968 = 1 - e^{-\frac{UA}{11.4}}$$

or

$$UA = \frac{39.5 \text{ B}}{\text{hr-F}} .$$

This value for UA falls well within the predicted range of 16 to 64 for UA.

Effectiveness Ratio and Prediction of Performance at Proposed Operating Conditions

$$E = 1 - e^{-\frac{UA}{mc}} .$$

From previous calculation,

$$UA = 39.5 \frac{\text{B}}{\text{hr-F}}$$

$$mc = 24.4 \frac{\text{B}}{\text{hr-F}}$$

$$E = 1 - e^{-\frac{39.5}{24.4}} = 0.80 .$$

Substitution in Equation (2) yields

$$t\ \text{gas out} = 0.80\ (115 - 32) + 32 = 98\ \text{F} \quad .$$

This prediction of outlet temperature is based on an assumption of steady flow through the heater. For an *RMV of 1 cfm* by the diver, breathing sinusoidally, the maximum gas flow can be shown to be π (RMV). *Thus effectiveness ratio at peak flow* rate will be:

$$E = 1 - e^{-\frac{39.5}{\pi(24.5)}} = .60$$

and, from Equation (2)

$$t\ \text{gas out} = .60\ (115 - 32) + 32 = 82\ \text{F} \quad .$$

Thus, ideally, the temperature of the gas leaving the heater will vary from 82 F at maximum inhalation flow to 115 F at no flow.

It must be emphasized that although these temperatures will be maintained at the heater, losses will occur between the heater and the diver unless effort is made to keep the flow path either heated or short.