CHAPTER 14

THERMAL CONDUCTANCE OF IMMERSED PRINNIPED AND SEA OTTER PELTS BEFORE AND AFTER OILING WITH PRUDHOE BAY CRUDE

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Abstract

Thermal conductance (C) of the sea otter and several species of pinniped pelts was determined during immersion, after oiling, and after cleaning. A (C) of 7 Watts • $Meter^{-2}$ • $°C^{-1}$ for the sea otter pup was the lowest measured in all controls. The highest was 58 W • M^{-2} • $°C^{-1}$ for the California sea lion. Most affected by oiling was the sea otter pup in which (C) doubled. Least affected was the sea lion in which no change in (C) occurred. Washing slightly reduced (C) of the adult otter and fur seal. The results indicate that even a light oiling would have marked detrimental effects on the thermoregulatory abilities of otters and fur seals at sea. The thermal effects of oiling on other adult pinnipeds while at sea would be slight.

Key words: Fur seal, sea lion, walrus, Phocidae, lanugo, groom, sea otter thermal conductance, thermoregulation

Introduction

The insulative quality of the fur of arctic and temperate mammals has been assessed (Scholander *et al.*, 1950a; Hammel, 1955). Its remarkable effectiveness is exemplified by the arctic fox, *Alopex lagopus*, whose thermal neutral zone extends below -40°C (Scholander *et al.*, 1950b). Aquatic mammals and birds, however, must face a more unconventional challenge than that of keeping warm just in air. They must also reduce heat loss in water where the heat conduction is tens of times greater.

Most marine mammals have a subcutaneous blubber layer which, combined with a remarkable peripheral vascular structure and an exquisite control of blood flow through the blubber and to the skin, results in an ideal substance for insulation. Not only is it a poor thermal conductor, but under circumstances of heat loading warm blood can pass through this insulator and dissipate heat at the skin's surface. Furthermore, the blubber functions simultaneously as a store for high energy fats. An important disadvantage to some species is the increased bulk it adds. The amphibious groups such as the pinnipeds are awkward when ashore. Perhaps because a thick layer of blubber would be a serious impediment to mobility, freshwater species such as muskrat, beaver and river otter rely primarily if not wholly on fur for insulation. This is the case for some marine mammals as well, i.e., fur seals and the sea otter. Why these marine mammals rely on fur as the primary barrier to heat loss in water is an interesting evolutionary question. Fur has some important disadvantages which include: 1) A considerable ammount of energy is expended in grooming. 2) In times of heat loading the heat cannot be dissipated over the entire body surface because of the fur barrier and this loss must be accomplished by way of the bare flippers. Consequently, these animals have a narrow thermal tolerance in aerial environments.

The characteristics of heat flux in aquatic animals have been the subject of several studies. The thermal conductance (C) of seal blubber was studied by Scholander *et al.*, (1950a), Hart and Irving (1959) and Bryden (1964). Flensed blubber was found to conduct about the same as asbestos, and the blubber of the living animal with its flow of blood was about 50% higher (Hart and Irving, 1959). Changes in (C) of dry and immersed pelts of beaver and polar bear also have been determined by Scholander *et al.*, (1950a). The influence of flow rate, guard hairs and undercoat on (C) has been assessed by Frisch *et al.*, (1974).

With the widespread use of supertankers to transport oil, and the proliferation of platforms for offshore drilling and pumping of oil, interest in the effects of oil on the insulative properties of marine birds and mammals has developed. Several recent studies have been addressed to this problem. McEwan and Koelink (1973) have studied mallard ducks and scaup. The metabolic response of muskrats before and after oiling has been tested (McEwan *et al.*, 1974). Most recently the effects of crude oil on ringed seals has been investigated (Smith and Geraci, 1975).

The purpose of this paper is to describe the effects of immersion, oiling and immersion, and cleaning with detergent and immersion on (C) of the pelts of several species of pinnipeds and the sea otter.

Materials and Methods

Fresh, blubber-free pelts from several species of pinniped were collected and kept frozen until the time for the heat flux measurements. The pelts studied are listed in Table 1. The pelts were mounted on wooden frames with enough stretching so that there was little slack in the skin. Thickness, measured by dial calipers, was difficult to estimate due to uneven fur loft.

TABLE 1. Thermal conductance of immersed pinniped pelts

P=pup; SA=subadult; & A=adult. Bracketed samples are from the same animal.

Family	Genus & Species(1)	Age	Pelt Thickness (Cm)	Fur Thickness (Cm)	Conductance ($W \cdot M^{-2} \cdot {}^{\circ}C^{-1}$)
Mustelidae	*Enhydra lutris*	P	2.2	1.9	7
	" " ⎫	A	1.1	0.7	26
	" "(2) ⎬	A	2.1	1.7	23
	" " ⎭	A	1.3	0.9	22
	" "	A	2.6	2.3	22
Phocidae	*Erignathus barbatus*	A	1.2	-	27
	Phoca groenlandica	A	0.4	-	52
	Lobodon carcinophagus	A	0.8	-	37
	Hydrurga leptonyx	SA	0.6	-	34
	Leptonychotes weddelli	P(3)	1.5	0.4	28
	" "	P(3)	1.5	0.4	28
Otariidae	*Zalophus californianus*	A	0.4	-	58
	Callorhinus ursinus ⎫	SA	1.0	0.5	26
	" " ⎬	SA	0.8	0.4	26
	" " ⎭	P	1.2	0.3	40
Odobenidae	*Odobenus rosmarus*	SA	2.5	-	15

(1) In accordance with the Marine Mammal Commission nomenclature list.
(2) Same fur sample as previous measurements but combed and fluffed.
(3) Pup long haired fur (lanugo).

The heat flux measurements were made with a Beckman-Whiteley heat flow transducer, Model T200-3. The transducer consists of a silver-constantan thermopile sandwiched between thin bakelite plates. Heat flow through the thermopile generates an electromotive force due to the difference in temperature between the thermocouple junctions of the thermopile. The output was measured with a Leeds and Northrup Model 8686 potentiometer.

Mounted on the bottom side of the transducer was a brass chamber with the edges and bottom surface insulated with 5 cm of styrofoam. Water at 37°C (< 0.1°C variation) was circulated from a Thermomix 1420 circulator. Over the top surface of the transducer was placed a 30 by 30 cm water bath with a thin (0.1 mm thick) sheet of plastic as the bottom of the container. The mounted pelts were bonded to the plastic sheet by means of a thin film of grease (Crisco). The pelt was then held tightly in place with four mounting brackets which pressed against the wooden frame. A Lauda/Brinkmann circulator K-2/RD pumped water into and out of the bath through two manifolds which distributed the water evenly across the pelt. Flow rate through the bath was 25 cm • min^{-1}. The water depth was about 3 cm. The water temperature selected was usually about 12°C, and the variation in temperature through the course of a run was 0.1°C. Plate (skin temperature) and water temperatures were read with a Leeds and Northrup 8686 potentiometer whose reference temperature source was a distilled water and ice slush. Conductance was computed as the heat flow per unit area divided by the difference in plate and water temperatures, and it was expressed in W • M^{-2} • $°C^{-1}$. In order to achieve thermal stability a run lasted from 8 to 12 hours.

After the initial run the pelts were "squeezed" dry and 10 to 20 ml (.02 ml • cm^{-2}) of Prudhoe Bay Crude oil was painted into the fur, except for the sea otter pup which was thoroughly drenched. The paint strokes ran with the grain on the fur. The pelt was left sitting for about 5 min and then rinsed with fresh water for 15 sec. It was then placed in the water bath.

Results

The fur of the three long-haired animals that we studied: the Weddell seal pup, *Leptonychotes weddelli*, fur seal, *Callorhinus ursinus*, and sea otter, *Enhydra lutris*, had quite different appearances from each other. The Weddell seal was a woolly, rather disheveled looking fur that wetted rapidly when immersed. The sea otter pelt had a woolly, loose appearance superficially, but a very dense underfur or wool. Kenyon (1969) cites an examination of the fur by Scheffer in which hair densities of 101,000 fibers • cm^{-2} were estimated. The fur did not lay as flat as that of the fur seal. It did seem more water repellent.

The fur seal pelt was a dense, smooth, orderly looking fur that was a water resistant barrier. Water penetrated slowly into the underfur. The wetting seemed to be hastened if the guard hairs were parted. We found that if the fur were pressed hard and the pressure advanced with the grain of the fur water was forced out and the underfur appeared dry. After watching fur seals groom we suspect that process may achieve similar results. The texture and density of hair fibers of the fur seal pelt were noted by Scheffer (1962). He found that the hair density of the mature pelt was 57,000 hairs • cm^{-2}, and that of the pup fur was 9000 hairs or fibers • cm^{-2}. He notes that 75 to 80% of the pup fur was underhair which is coarser than underfur or wool of older animals. Scheffer also noted that when it rains the pups soak to the skin. Considering these differences in physical characteristics the greater (C) of the pup pelt compared to that of the subadults is expected (Table 1).

TABLE 2. Thermal conductance of oiled and immersed pelts.

Symbols are the same as Table 1.

Subject	Age	Pelt Thickness (Cm)	Conductance (W • M^{-2} • $°C^{-1}$)	Multiple of Control
E. lutris	P	1.1	15	2.1
" " (1)	A	-	26	-
" " (2)	A	-	29	1.3
" " (2)	A	-	26	1.1
E. barbatus	A	1.2	27	1.0
L. weddelli	P	0.9	42	1.5
Z. californianus	A	0.4	56	1.0
C. ursinus	SA	1.0	53	2.0
" "	SA	0.8	45	1.7
" "	P	0.7	54	1.4

(1) Naturally oiled with heavy crude.
(2) Compared to combed and fluffed fur.

Of all the sea mammal pelts tested the best insulator, or the one in which (C) was the least was that of the sea otter pup (Table 1). Its conductance value was 7 W • M^{-2} • $°C^{-1}$. The next lowest (C) was the skin of the walrus, *Odobenus rosmarus*. Several species had about the same (CO) values of between 20-30 W • M^{-2} • $°C^{-1}$. These were the adult sea otters, subadult fur seals, Weddell seal pups, and the bearded seal, *Erignathus barbatus*. The highest (C) was recorded from the California sea lion, *Zalophus californianus*, pelt of 58 W • M^{-2} • $°C^{-1}$.

The most profound effects of oiling were on the sea otter pup and the subadult fur seal in which (C) increased 2.1, and 1.7 to 2.0 times, respectively (Table 2).

The (C) of the naturally oiled sea otter, an animal that apparently swam through an oil slick and whose partially oiled carcass was later found, was nearly the same as the pelt we oiled with Prudhoe Crude. However, the density of the two oils was different. The Prudhoe Crude was much lighter, was not tarry and did not clump the fur. Oil caused no change in (C) of the bearded seal or California sea lion.

The most improvement due to cleaning was in the fur seal, but the (C) was still 1.5 times greater than the control (Table 3). However, the pup fur seal pelt had a lower (C) after cleaning than the control. This was probably because the loft due to fluffing of the fur after cleaning and drying was better in the cleaned than in the control pelt. The (C) of the adult sea otter pelt was about the same as the control. The pup sea otter pelt deteriorated and no measurements were possible. There was no change in the sea lion.

TABLE 3. Thermal conductance of cleaned and immersed pelts.

Cleaning agent was Basic-H detergent.† Symbols the same as Table 1.

Subject	Age	Pelt Thickness (Cm)	Conductance (W • M^{-2} • $°C^{-1}$)	Multiple of Control
E. lutris	A	1.9	21	0.9*
" "	A	2.6	20	0.9*
Z. californianus	A	0.4	56	1.0
C. ursinus	SA	1.0	38	1.5
" "	SA	0.9	40	1.5
" "	P	1.4	34	0.9

*Compared to combed and fluffed fur.
†Shaklee Corporation

Discussion

The pelt of the nearly hairless walrus was a poor conductor because the skin was so thick, nearly 5 cm. In the live animal any blood flowing through the skin would increase its (C). No doubt the most important thermal barrier would be the thick subcutaneous blubber layer.

The (C) through the skin and pelage of the earless seals (phocids) and the sea lion were high compared with the sea otter and fur seals. This is not surprising considering that seals and sea lions possess a thick, subcutaneous layer which serves as the main barrier to heat loss. It was found previously that (C) through skin, fur and 4 to 5 cm of blubber was about 3.5 W • M^{-2} • $°C^{-1}$ in the ringed seal, *P. hispida* (Scholander *et al.*, 1950a). This is a tenth of the (C) we measured in the skin and fur only of seals. However, as we mentioned earlier Hart & Irving (1959) determined that blubber in the live animal is not so effective an insulator. (C) is about 50% higher than the value previously determined by Scholander *et al.*, (1950a).

For a short time after birth all species of polar seal pups possess a long haired pelt called lanugo. This coat functions as the main barrier to heat loss until a thick blubber layer develops as the pup nurses. Until the blubber layer develops the pups usually do not enter the water. If they were to do so the pelt quite likely would wet through and there would be a large heat loss such as that which we measured of 28 W • M^{-2} • $°C^{-1}$ for Weddell seals. Considering the thermal gradient across the skin and fur would be about 37°C; that is the difference between the body temperature and the sea water temperature, this represents a total output of over 1000 W • M^{-2}. Estimating that a 27 Kg pup has a surface area of about 0.93 M^2 (Meeh's surface area equation, SA = 10 $W^{0.67}$, Drent & Stonehouse, 1971), the total heat loss would be 930 W. This is about twelve times the predicted heat production based on body weight (Hart & Irving, 1959). The newborn pups probably can not sustain such a high metabolic rate and thus they could not tolerate immersion long.

Thermal conductivity results seem unrealistically high for control pelts of the sea otter and fur seal. Based on calculations similar to those of the Weddell seal the (C) of the pelt is more than five times greater than the expected heat production of the animal. Apparently some important property of the pelt is lost after removal from the animal. The important missing element may be grooming. Without this activity water may leak into the fur, and is not removed. Thus, any agent that increases the wettability of the fur will increase (C) of the pelt.

The various pelts studied might be grouped into three major categories: 1) The sparsely furred, wettable pelts of sea lions and seals, which depend wholly upon a thick blubber layer for insulation rather than upon fur. 2) The fur seal pelt is a dense fur that may gradually wet unless groomed. This fur is probably the sole insulation even though some subcutaneous fat is present. 3) The sea otter has no subcutaneous fat and the pelage is the barrier to heat loss. With this grouping in mind, Fig. 1 summarizes the effects of oiling and cleaning of adult sea otter and sea lion and subadult fur seal.

Thermal conductance is very high in the sea lion pelt. Oiling and washing do not alter the insulative properties much. These results are consistent with the nature of their fur. Such an effect would be similar in all those species in which blubber was the primary insulator.

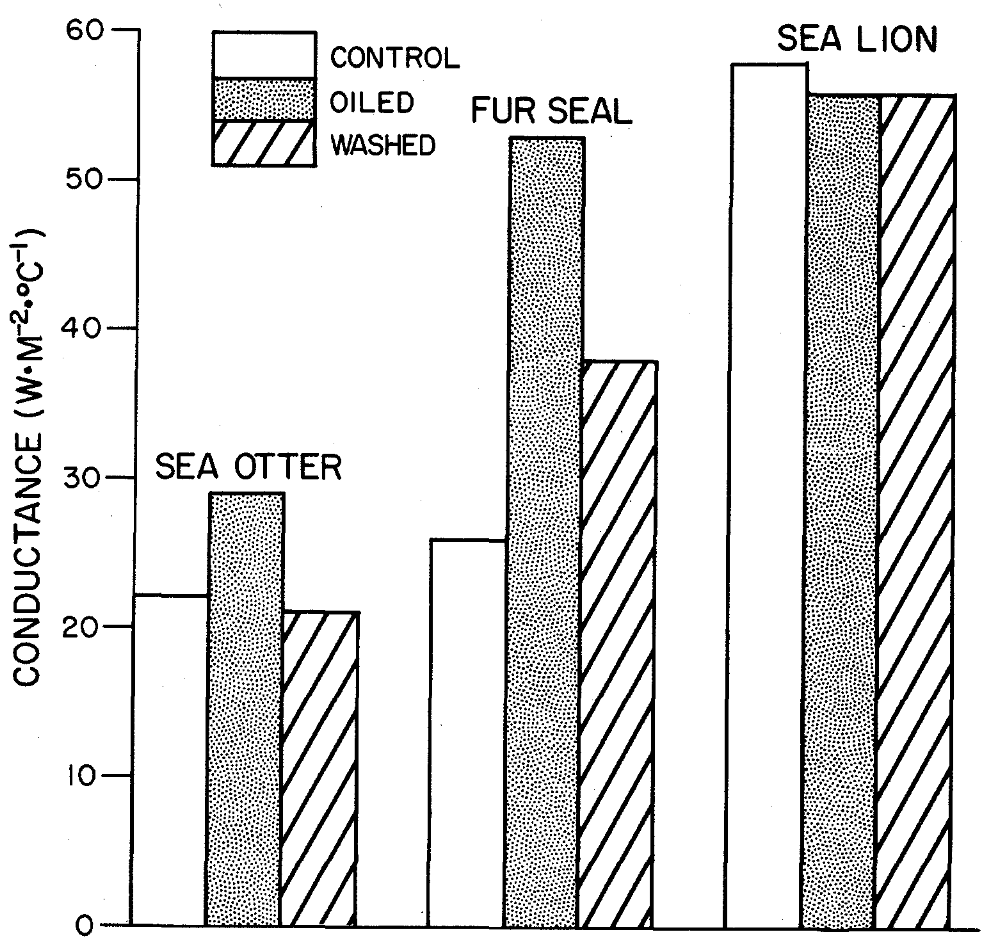

Fig. 1. Thermal conductance of sea otter, fur seal and sea lion pelts during normal immersion, after oiling, and after cleaning.

The increase in (C) in the sea otter and especially the fur seal after oiling (Fig. 1, Table 2) is a serious degradation of the fur. If the animals are unable to reverse this effect by some means, such as grooming, they probably could not endure cold water immersion long. Washing the fur, particularly that of the fur seal does not decrease (C) much.

Conclusions

The method of determining heat flow through pelts that was described in this study is an uncomplicated way of obtaining relative information about conductance. A shortcoming of this technique is that it tells nothing about what effects the behavior of the animal may have on conductance, especially grooming. Therefore, the relative effects of oiling and cleansing may be substantially different in the living animal.

A mild oiling of the pelt with a light crude oil does not increase heat loss during immersion significantly in seals and sea lions. The (C) of the pelts of the otter and fur seal were unrealistically high even in the controls. This is suspected to be due to loss of water repellency for some unknown reason. These results emphasize the importance of pelt integrity and the calamitous effects of its loss. Oiling increases the (C) of the pelt presumably by reducing water repellency. The consequences would be gravely serious for these species if they were not able to overcome quickly the oiling affects. Removing the oil from the fur with a detergent does not improve the quality much.

Acknowledgements

We wish to thank those people who contributed pelts to this study. They are: Dr. L. H. Cornell, Sea World of San Diego; Dr. D. D. Hammond, Oceanic Park, Ltd., Hong Kong; Dr. D. H. Kerem, Aba Khousky School of Medicine, Haifa, Israel; and Dr. Karl Schneider, Alaska Department of Fish & Game. Dr. H. T. Hammel, Scripps Institution of Oceanography, generously loaned equipment for this study. Dr. R. L. Gentry, Marine Mammal Division of the Northwest Marine Fisheries Center, provided considerable help in many aspects of the research and without his support the project would not have been possible.

This project was supported by National Oceanic and Atmospheric Administration Outer Continental Shelf Environmental Assessment Program. R. W. Davis was supported by Biomed research support grant PHS RR 05665-09 to Dr. J.H. Moxley and M. A. Castellini was supported by a Regent's Fellowship.

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