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THE USE OF IMPERMEABLE MUKLUKS IN THE COLD: AN INITIAL INVESTIGATION

by

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ABSTRACT

A series of laboratory and field trials was conducted to compare standard permeable CF mukluks and experimental impermeable mukluks with respect to comfort, moisture accumulation due to foot perspiration and techniques for use. It was found that if properly dried overnight, there was little difference between the two types of mukluk. However, it was shown that conditions inside a tent in the field in winter are such that drying is very difficult and moisture accumulation over an extended period of time may cause significant problems with either type of footwear. No subjective differences between permeable and impermeable mukluks were observed.

RÉSUMÉ

On a procédé à une série d'expériences en laboratoire et à l'extérieur pour comparer les mukluks perméables réglementaires des Forces canadiennes à des mukluks imperméables d'un nouveau genre. Le confort, l'accumulation d'humidité causée par la sudation des pieds et le mode d'emploi ont servi de critères de comparaison. On a constaté que, s'ils peuvent sécher convenablement pendant la nuit, ces deux types de mukluks ne présentent guère de différence. Il a toutefois été établi que les conditions régnant à l'intérieur des tentes en hiver sont telles qu'elles ne favorisent d'aucune façon le séchage et que l'accumulation d'humidité pendant une longue période peut provoquer de graves ennuis avec l'un ou l'autre genre. Il n'existe donc aucune différence appréciable entre les mukluks perméables et les mukluks imperméables.

INTRODUCTION

The standard item of cold weather footwear used by the Canadian Forces when operating in Northern or Arctic regions is the rubber-soled, moisture-vapour-permeable, nylon mukluk. These have been designed for use under conditions of dry cold and do not possess water-repellent properties (excepting the rubber sole), since it is generally acknowledged that vapour barriers are not to be used in Arctic clothing. The resultant moisture accumulation inside a vapour barrier decreases the insulative value of clothing and causes an increased heat loss from the body.

Under conditions of wet cold when water or melted snow may be present, moisture can be absorbed into the CF mukluk, causing foot discomfort. Serious frostbite can result if conditions are such that wetted footwear cannot be changed immediately.

It was felt that the advantages offered by the absence of a vapour barrier in the standard permeable mukluks were offset by the dangers inherent when these were used under wet cold conditions. If the mukluks were waterproofed, they could be used in snow when temperatures rose above freezing as well as under dry cold conditions, provided that moisture accumulation inside due to foot perspiration was not excessive. To investigate the feasibility of this concept, a limited number of moisture-impermeable, polyurethane-coated mukluks were developed by DCGEM and forwarded to DREO for evaluation.

The investigation at DREO was undertaken to evaluate moisture-impermeable, polyurethane-coated mukluks in comparison with standard-issue permeable nylon mukluks to determine their suitability for use in the Canadian Forces with regard to comfort, moisture accumulation (due to foot perspiration) and techniques for use.

DESCRIPTION OF MUKLUKS

The following is the description of the standard permeable mukluk found in "Combat Clothing and Equipment, 1972", a Canadian Forces catalogue prepared by DCGEM.

Item Name - Boots (Mukluk) Extreme Cold Weather
8430-21-104-6909

Concept of Use - Under extreme cold dry conditions as part of cold weather clothing ensemble.

Description - A four component assembly worn with trousers tucked inside fastened with "D" ring lace closure. Rubber bottom is patterned for traction over ice and snow.

Materials Used - Polyester fabric, synthetic rubber, "D" rings of acetal copolymer, nylon laces. Wool/Viscose 31 oz/sq yd (0.836 sq m) duffle cloth (double). Saran 4 ply monofilament mesh removable insole. Felt, removable insole, 90% wool, 10% cellulosic fibre.

Colour - White.

Dimensions - 13-1/2" to 16 1/2" (45.7 to 53.3 cms) in height according to size.

Weight - Approximately 6 lbs (2718 gms) per pair complete.

The experimental impermeable mukluk is similar to the above, except that a one-ounce-per-square-yard coating of white pigmented polyurethane has been applied (knife-coated and heat cured) to the polyester twill fabric.

In this report, the term "mukluk assembly" means:

boot, mukluk
sock, wool frieze
insole, Saran
insole, felt.

The components of the mukluk assembly are shown in Figure 1.

EXPERIMENTAL PROCEDURES AND RESULTS

The experimental investigation of the use of permeable and impermeable mukluks in the cold was conducted in several distinct stages. Due to supply problems initially, and the fact that it was considered necessary to obtain information while the mukluks were worn outdoors during winter field trials, the investigation was carried out intermittently over periods of several months. The experimental procedures used and the results obtained during each of the separate stages are described below.

Cold Chamber Trial

Initially, one pair of impermeable mukluks was obtained for evaluation. Two test subjects were each fitted with one impermeable and one permeable mukluk and the following test procedure was followed on several successive days.

1. After drying in the laboratory overnight (temperature = 21±1°C, RH = 30 ± 10%), the individual components of each type of footwear were weighed.

Fig. 1. The Canadian Forces Mukluk.

2. At 09:00, thermistor-type temperature probes were fitted to the great toe of each foot of the subjects. The mukluks were donned and worn for the remainder of the morning as the subjects carried out their normal duties.

3. At 13:00 the test subjects entered the DREO Cold Chamber which was maintained at a constant temperature of -31°C. In the chamber, the subjects remained idle for 30 minutes, walked on a treadmill at 3 mph for 30 minutes and then remained idle for a further 30 minutes. During the period in the cold chamber, foot temperatures were measured at 10-minute intervals.

4. At 14:30, the subjects left the cold chamber and removed the footwear. The individual components of each mukluk were weighed immediately and the change in weight after wearing for 5-1/2 hours was determined.

Figure 2, a graph of the foot temperature of one subject versus time while in the cold chamber, is representative of the measurements made during the trial.

A summary of the data obtained during this trial is presented in Table I. Included are the total daily changes in weight and the differences between initial and final foot temperature observed during 90 minutes in the cold chamber. Statistical analysis of the data using the Student-Fisher t-test indicates that for each of the parameters measured (change in weight and change in temperature) there is a significant difference between the permeable and impermeable mukluk at the $p=0.005$ level.

Investigation of "Wool Swatch" Technique

In order to obtain information about moisture distribution and relative humidity inside the permeable and impermeable mukluk, it was proposed that the "wool swatch" technique be used. This technique, described by a number of investigators (1-4), has been used to determine the relative humidity at various locations inside boots and shoes during wear. Briefly, it consists of establishing a calibration curve for a given sample of woollen material, so that relative humidity may be measured in terms of the moisture regain of the wool. Unfortunately, attempts to apply this technique to the current problem were unsuccessful. Details of the investigation at DREO are given in Annex A.

Trials in the Laboratory

In order to obtain additional information regarding the total moisture accumulation inside each type of mukluk due to foot perspiration, two one-week laboratory trials using five test subjects were conducted. At 09:00 every day during the trial, after the individual components of the footwear assemblies had been weighed, each test subject donned one permeable and one impermeable mukluk. Due to unseasonably warm weather (+5°C) and wet outdoor conditions, activities during the wearing period were restricted to normal indoor duties. After a six-hour wearing period, the footwear was removed and the components were reweighed.

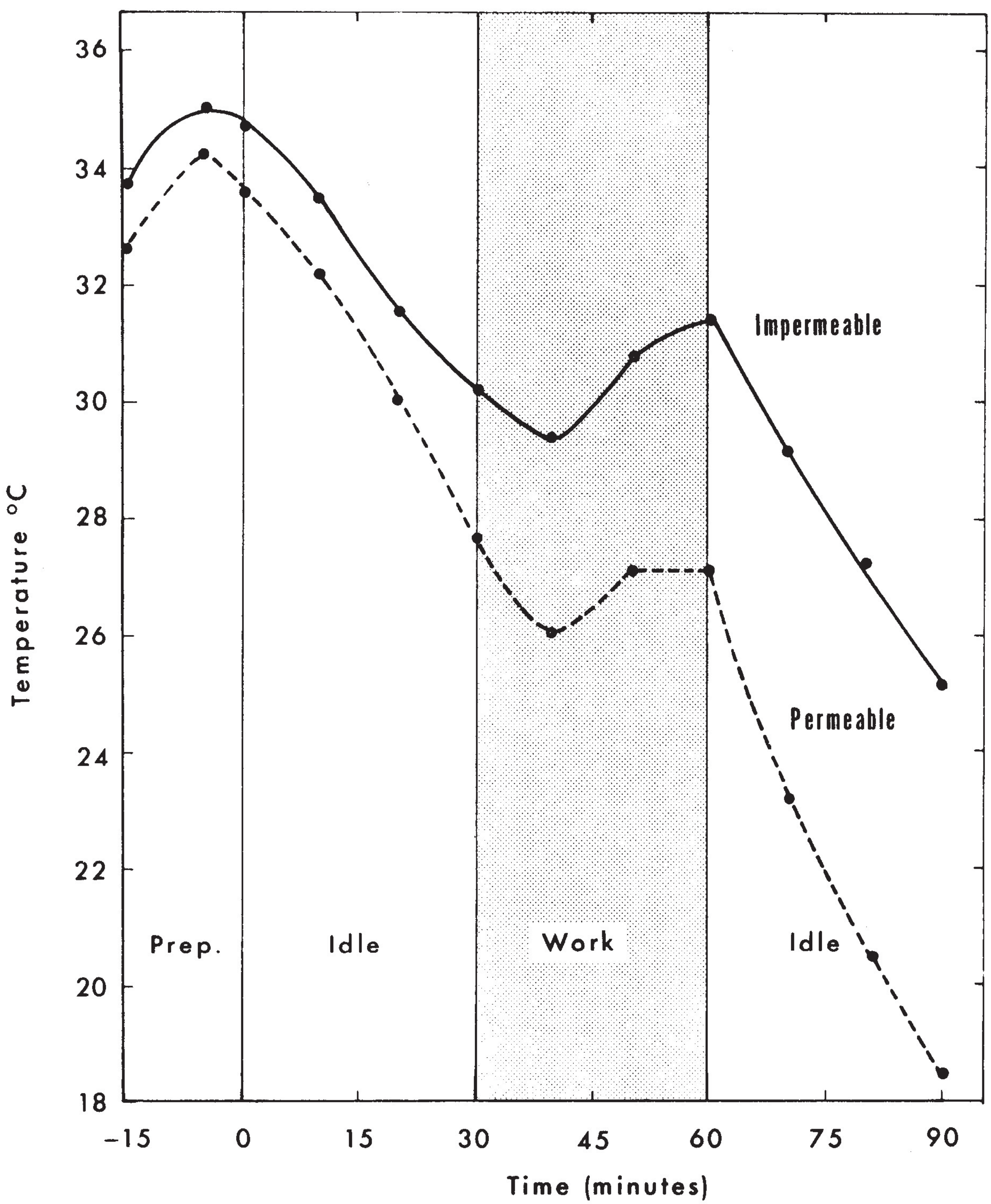

Fig. 2 Foot Temperature vs Time in Cold Chamber (Ambient Temperature = -31°C)

TABLE I

Observations During Cold-Chamber Trial

Run No.	Subject No. 1				Subject No. 2			
	Weight Gain (gm)		Decrease in foot temp. (°C)		Weight Gain (gm)		Decrease in foot temp. (°C)	
	Perm.	Imp.	Perm.	Imp.	Perm.	Imp.	Perm.	Imp.
1	26.5	33.1	13.6	8.8	18.9	19.2	12.6	10.1
2	29.5	39.7	14.0	7.6	20.6	26.7	6.4	5.0
3	37.4	47.0	10.6	9.6	21.8	27.0	5.8	5.6
4	37.2	45.1	15.2	9.6	24.9	34.1	7.4	6.1
5	-	-	-	-	17.0	20.3	6.7	5.2
6	-	-	-	-	22.8	24.4	8.5	7.2
7	-	-	-	-	22.4	23.8	11.8	8.2
8	31.0	44.6	-	-	24.5	30.7	8.2	10.3
9	30.6	32.9	13.9	9.2	17.7	19.2	6.3	5.1
10	34.3	41.1	15.5	8.7	-	-	-	-
11	43.4	47.6	16.6	12.4	26.6	34.9	4.7	3.8
12	29.9	45.4	15.1	10.2	21.3	25.5	-	-
13	29.0	35.4	17.0	12.0	26.5	29.1	7.2	5.6
mean	32.9	41.2	14.6	9.8	22.1	26.2	7.8	6.6

CF personnel are taught that, when drying wet or damp footwear inside a shelter, the components of the mukluk assembly should be separated to aid the drying process (5). A secondary objective of the laboratory trial was to determine the effect on drying of separating the components when these were dried in the laboratory overnight. During the first week of the trial, the mukluk components were left assembled while in the laboratory overnight. During the second week, the individual components were placed separately on the laboratory bench. The indoor temperature and relative humidity overnight during this period were 21 ± 1°C and 30 ± 10%, respectively.

Figure 3 (first week) and Figure 4 (second week) indicate the mean variation in total moisture content of each type of mukluk during each week of the trial. The mean weight at 09:00 (AM) and 15:00 (PM) each day is plotted. These points are joined by straight lines to emphasize the trend of the variation. Points along the lines are not necessarily indicative of intermediate values. Also, for clarity, the range of values from which each of the means was calculated is not shown in the figures. Because of differences between subjects, variation from the mean was often ±50% or greater, although the general trend for individual subjects was similar.

Results presented in Figure 3 and 4 indicate that the mean daily moisture accumulation in the impermeable mukluk was consistently greater than in the permeable mukluk. During six hours wear each day, approximately 5 grams more moisture accumulated in the impermeable type. When the mukluk components remained assembled while drying in the laboratory overnight, the impermeable mukluk did not dry as well as the permeable type did. The excess moisture remaining in the impermeable mukluk was about the same as the excess accumulation measured after the wearing period each day. The cumulative effect illustrated in Figure 3 was observed, resulting in approximately twice as much moisture remaining in the impermeable mukluks at the end of the four-day trial. The long-term significance of this effect was not studied.

When the components of the mukluks were separated to dry in the laboratory overnight, both the permeable and impermeable types reached approximately the same degree of dryness, even though the impermeable mukluk initially contained about 5 grams more moisture. This result was observed on several successive days (Figure 4). In relation to the total weight of the mukluk assembly (~ 1000g), the excess moisture measured in the impermeable mukluk each day may be considered insignificant.

It should be noted that throughout this trial it was found that there was no subjective difference in feelings of warmth vs coolness or wettness vs dryness between permeable and impermeable mukluks.

Field Trial

Observations made during the laboratory trials described above indicated that, if the components of the mukluk assemblies were separated at the end of the wearing period and left to dry overnight, there was very little difference in the moisture content of either the permeable or impermeable type during the day. However, drying conditions in the laboratory and those likely to be encountered in the field in mid-winter are vastly different. The atmosphere inside a tent during a winter exercise is constantly being

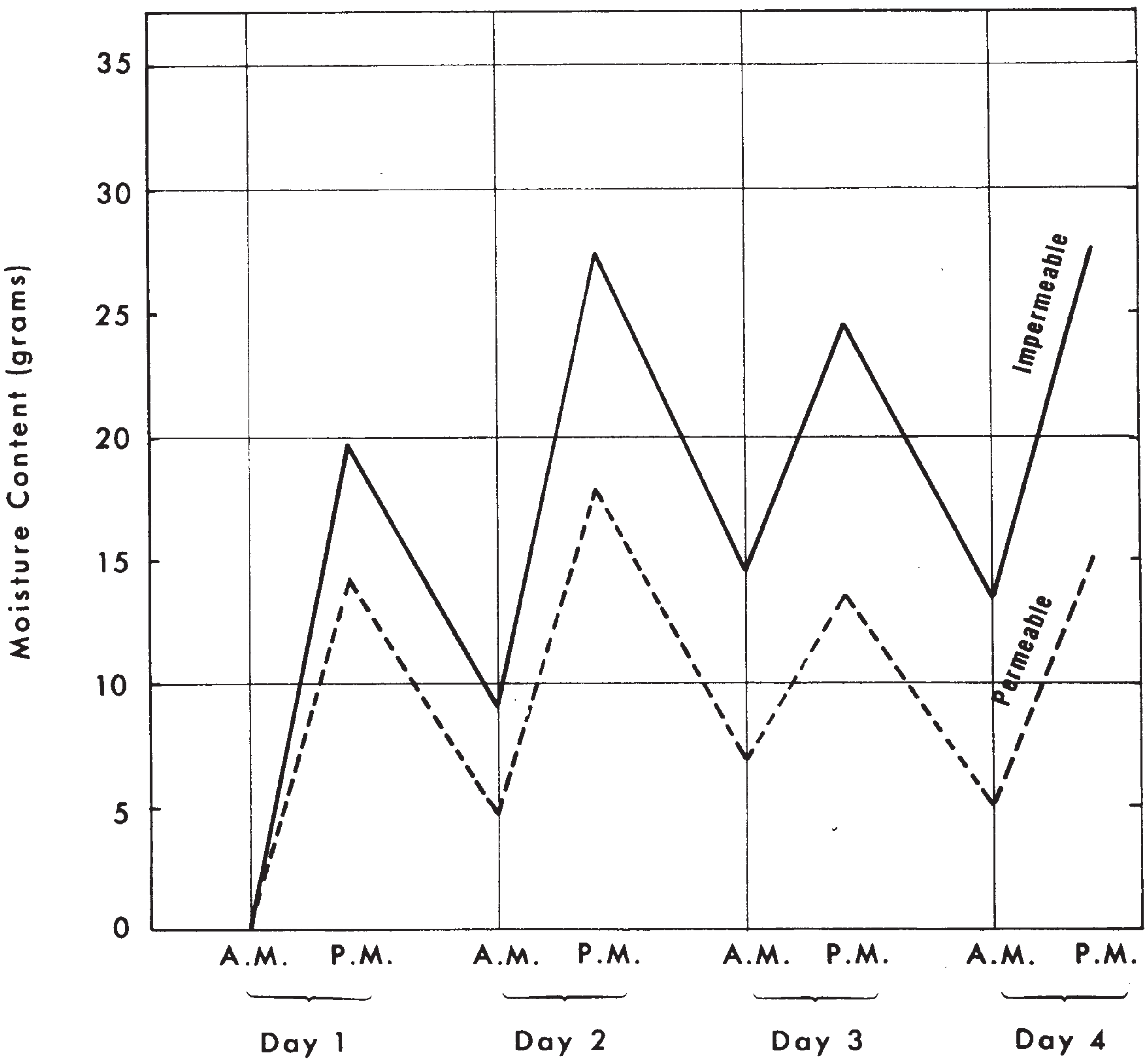

Fig. 3 Mean Variation in Moisture Content of Mukluks During First Week (Components Assembled to Dry Overnight)

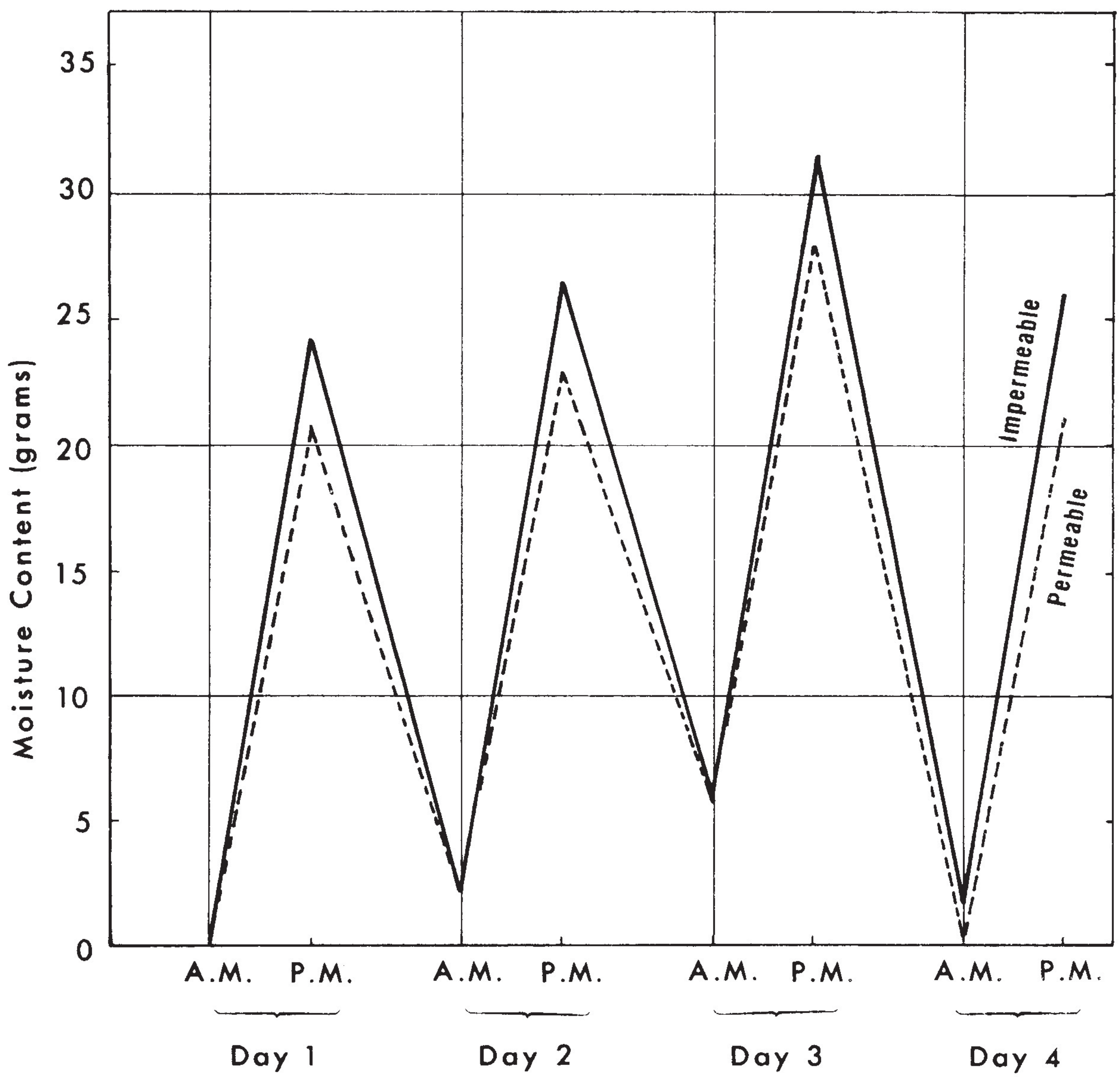

Fig. 4 Mean Variation In Moisture Content of Mukluks During Second Week (Components Separated to Dry Overnight)

saturated with moisture from a number of sources including steaming cooking pots and the exhaled breath of members of the tent group. Even if stoves are extinguished during sleeping periods, exhaled breath contributes moisture to the ambient air. Frost is often observed on the inside walls of the tent. Under such conditions, is there reason to expect that items of clothing hanging up to dry will actually do so?

To obtain a measure of the effectiveness of "drying" the components of footwear assemblies by hanging them overnight in a tent, a small field trial using four test subjects was conducted using a CF 5-man Arctic tent erected at the DREO Quiet Site, a remote location situated about five miles from the DREO Shirley Bay Laboratories. As in the previous trials discussed in this report, each subject wore one permeable and one impermeable mukluk. The schedule listed below was followed on four successive days.

Time	Activity
12:00	Subjects arrive at laboratory, don mukluks (individual components previously weighed), carry on with normal indoor duties.
15:30	Subjects return to their homes wearing mukluks. (Mukluks are not removed until late evening.)
19:00	Subjects travel to DREO Quiet Site, light lamps and stoves in tent, boil water, prepare sleeping bags, etc.
22:30	Mukluks removed, components weighed. Socks, wool freize, insoles and socks, wool hung in tent at about the 4-foot level.
23:00	Stoves and lamps extinguished, subjects sleep.
07:00	Subjects awake, mukluks weighed and placed in moisture. impermeable plastic bags. Tent readied for evening. Subjects dismissed until 12:00.

Table II is a summary of temperatures observed during the trials. Temperatures inside the tent were measured using a maximum/minimum thermometer located on the centre pole, approximately five feet above the floor.

Results observed during the field trial are quite different from those obtained in the laboratory. During the field trial, when the mukluks were worn for periods of 10-1/2 hours under a combination of indoor and outdoor conditions, the mean moisture accumulation in the impermeable mukluk was about 20 grams greater than in the permeable mukluk (versus 5 g in 6 hours in the laboratory). The cumulative effect observed for the impermeable mukluk during the laboratory trial was measured for both types of mukluk during the field trial.

The most important result of the field trial is the observation that, in general, the mukluks do not dry when hung up overnight inside a tent outdoors during winter. In fact, the opposite is true. Generally, the mukluks increased in weight during the "drying" period. Especially in the case of the permeable mukluk, the increase in weight due to accumulated moisture was often greater overnight than during the wearing period. In some instances, the impermeable mukluk lost weight overnight while the permeable mukluk increased in weight during the same period. This effect was probably caused by the materials coming to moisture equilibrium with the atmosphere

TABLE II

Temperatures Observed During Field Trial

Date	Time	Temperature (°C)		
		Outdoors	Inside Tent*	
			Maximum	Minimum
Feb. 25	23:00	-9	>55	
26	07:00	-19		-11
26	23:00	-17	>55	
27	07:00	-19		+6**
27	23:00	0	>55	
28	07:00	-3		0
28	23:00	+6	>55	
Mar. 1	07:00	+3		+7

* five feet above floor
** catalytic heater used inside tent overnight.

Figure 5 illustrates the mean variation in total moisture content of each type of mukluk during the trial. The mean weight at 07:00 (AM) and 23:00 (PM) each day is plotted. As discussed for Figures 3 and 4, the points are joined by straight lines to emphasize the trend of the variation, and the range of values for each point is omitted.

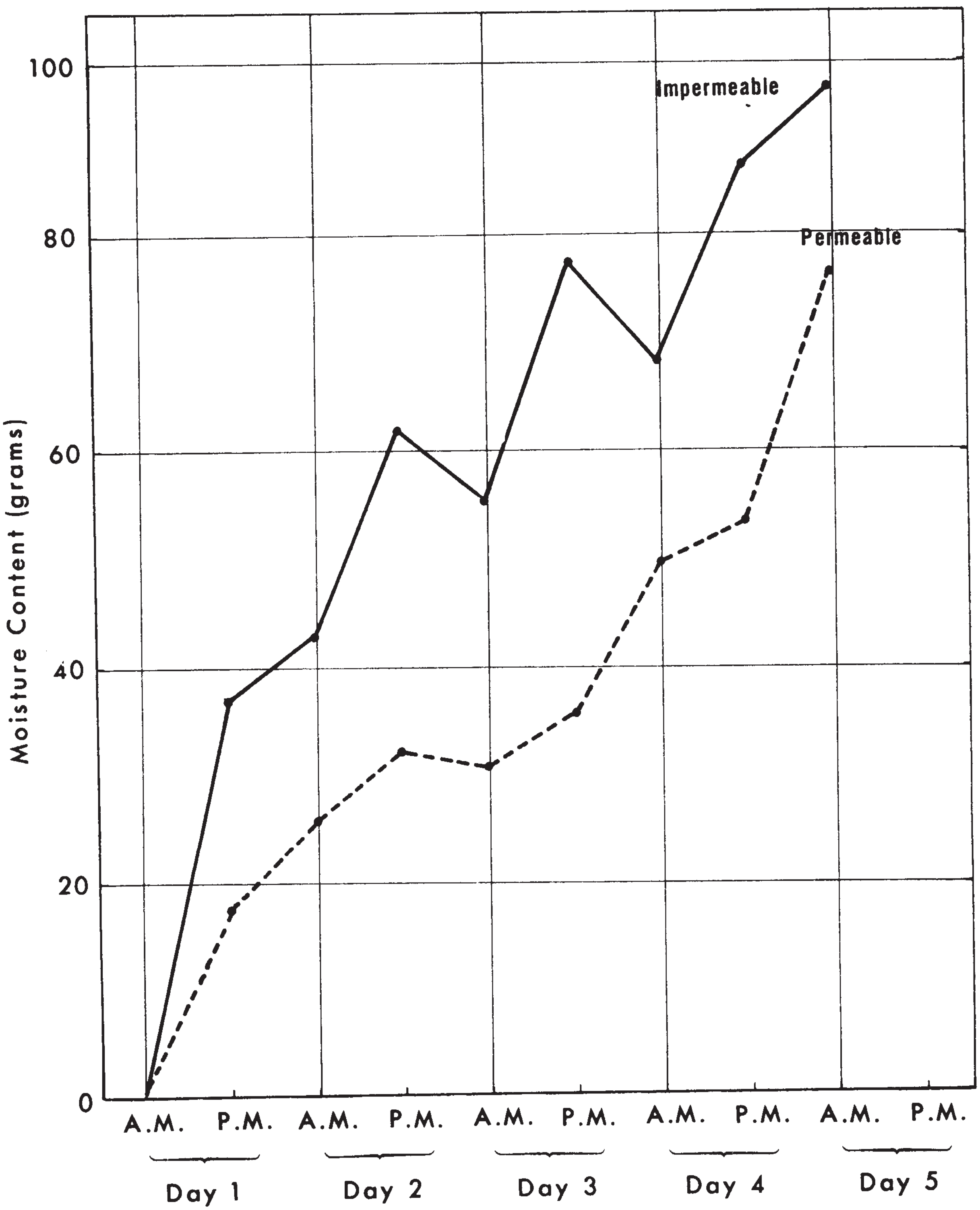

Fig. 5 Mean Variation in Moisture Content of Mukluks During Field Trial

inside the tent (i.e. initially the permeable mukluk contained less moisture than the atmosphere and thus gained weight during the "drying" process while the impermeable mukluk was saturated with respect to the atmosphere and thus lost weight as it approached equilibrium).

It should be noted that the moisture content of both types of mukluk continued to increase throughout the trial and did not appear to have reached a maximum value by the end of the week. It is also important to note that although the total moisture content approached 10% of the total weight of the mukluk by the end of the trial, none of the test subjects was able to detect any difference in feelings of warmth vs coolness or wettness vs dryness between the permeable and impermeable mukluks.

DISCUSSION

The original aim of the investigation at DREO was to evaluate moisture impermeable polyurethane coated mukluks in comparison with standard issue permeable nylon mukluks to determine their suitability for use in the Canadian Forces with regard to comfort, moisture accumulation and techniques for use. To date, the investigation has yielded the following information in each of the three specific areas of interest.

Comfort

In each of the several wearing trials described in this report (viz., cold chamber trials, laboratory trials, one-week field trial), no subjective difference in comfort between the permeable and impermeable mukluk was reported by any of the test subjects. Objective temperature measurements indicated that in general, subjects' feet were a few degrees warmer in the impermeable mukluk. Occasionally during the laboratory trials, subjects observed that their feet were uncomfortably warm. However, these situations were invariably reported when one mukluk of each type was being worn, i.e. excessive warmth could not be attributed to differences in the type of mukluk.

Additionally, six pairs of the waterproofed CF mukluks were worn during a DCIEM/DCGEM field trial in the St. Elias Mountains of the Yukon Territory in 1972. No cases of foot discomfort are mentioned by Hartlin and Gray in their report of this trial (6). They note that the mukluk was chosen in preference over individually selected items of footwear by all members of the test team and that no cases of wet feet were reported although temperatures rose above freezing on several occasions. They recommend that if additional testing proves that there are no undesirable characteristics in extreme cold, the mukluks should be adopted as standard cold-weather footwear.

Moisture Accumulation

In each of the wearing trials conducted at DREO, it was found that moisture accumulation due to foot perspiration was 20 - 30% greater in the impermeable mukluk. Statistical analysis of the data from the cold-chamber trial indicated that the greater accumulation in the impermeable mukluk was mathematically significant for each test subject. However, in many cases the total accumulation was only a few grams and the physical significance of the additional moisture in the impermeable mukluk was not considered to be important. Although it is known that physically, the thermal resistance (insulative value) of clothing decreases as moisture content increases, the physiological significance of increased moisture in the mukluk (in the amounts measured in our experiments) is unknown. Although the moisture accumulation in the above case was mathematically significantly greater in the impermeable mukluk, the foot was significantly warmer. It would appear that under the conditions of these experiments the impermeable mukluk acts to retain heat as well as moisture. Subjectively, no difference in moisture accumulation or foot temperature in the two types of mukluk could be detected.

Folk and Peary (7), in their work on penetration of water into the human foot, have shown that men can wear impermeable barriers on their feet for several days without discomfort. They present evidence which indicates that moisture accumulates under an impermeable barrier worn on the foot until an equilibrium is reached, apparently due to repenetration of water into the foot. After this time, it appears that sweating occurs at normal or near-normal rates and is not suppressed as might be expected. Although most of Folk and Peary's experiments were performed at a laboratory temperature of 80°F, their findings must certainly be considered when further studies of Canadian Forces Arctic footwear are planned.

The most important result of the current investigation is the observation that instead of losing moisture when hung up to dry inside the tent overnight, the mukluks increased in weight. This phenomenon was not dependent on the type of mukluks used and would likely be observed with any textile material "dried" under similar conditions. In several instances the mukluks picked up more moisture from the atmosphere during the "drying" period than they did from the feet of the test subjects during the wearing period. Even during active periods when stoves and lamps are operating and the temperature near the apex of the tent may be in excess of 50°C, drying may not occur because of the presence of water vapour created by boiling water, cooking food and burning fuel. It is important to note that at saturation (relative humidity of 100%) one cubic meter of air at 50°C contains 83 grams of water vapour whereas at -30°C the same volume of air will contain only 0.5 grams.

Techniques For Use

The investigations described in this report indicate that if either the permeable or impermeable mukluks are used in a proper manner there is very little difference between them. When these were compared on a daily basis, it was found that only a few more grams of moisture due to foot perspiration accumulated in the impermeable type. If the components of the mukluk were separated to dry overnight in an atmosphere with a low relative humidity, both types reached the same degree of dryness and the excess moisture retained in the impermeable mukluk after being worn during the day was not sufficient to create any problems.

However, it was found that the relative humidity of the atmosphere inside a tent in mid-winter may be such that drying does not occur even though the temperature is relatively high. In such cases no benefit will be gained if the components of the mukluk assemblies are separated and hung up to dry. In fact the mukluks may absorb additional moisture from the air. This could lead to serious problems if it became necessary for CF personnel to wear mukluks continuously for several days without having the opportunity to dry footwear in an atmosphere with low relative humidity. This situation should be studied in greater detail to determine at what level and under what conditions moisture accumulation becomes a serious problem.

CONCLUSIONS

It was found that when permeable and impermeable mukluks worn by test subjects were tested comparatively, there was greater moisture accumulation due to foot perspiration in the impermeable type. In general the amount of excess moisture was only a few grams and the physical significance of this was not considered to be important. Especially if one is able to dry the components of the mukluk assemblies in an atmosphere of low relative humidity, there is little difference between the permeable and impermeable type.

It was also found that due to the high relative humidity that usually exists inside a tent during a winter exercise, conditions are often such that mukluks do not dry but pick up additional moisture when hung up overnight in the tent.

Throughout the testing described in this report, no subjective differences in feelings of warmth versus coolness or wetness versus dryness between permeable and impermeable mukluks were reported.

RECOMMENDATIONS

Observations made during the course of the evaluations described in this report suggest that future investigations be made in the following areas:

1. Laboratory and cold-room trials should be conducted to determine the level at which moisture accumulation due to foot perspiration causes significant problems. The relationship between significant moisture accumulation and ambient temperature should be studied.

2. Additional cold-weather field trials with controlled activities should be conducted to determine approximately how long mukluks may be worn in the field without proper drying before moisture accumulation reaches the significant level. The effect of temperature should be included.

3. Convenient means to monitor and obtain a continous record of the temperature distribution and moisture content of the atmosphere inside a tent in the field during a winter exercise should be devised. Information from measurements of this type may be used to determine at which times and under what conditions the relative humidity inside the tent is low enough to allow the drying of footwear and other items of Arctic clothing and equipment.

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ANNEX A

Investigation of "Wool Swatch" Technique

During the course of the investigations at DREO, it was suggested that the "wool swatch" technique (1-4) be used to obtain information regarding the distribution of moisture inside each type of mukluk. The method consists of determining the moisture regain (change in weight due to absorbed moisture) of small pieces of wool and converting this to values of relative humidity using previously determined calibration curves.

Several samples of woolen material and two samples of rayon were obtained. These are identified as follows:

Wool, Hudson Bay
Wool, Serge
Cloth, Melton, DRB
Wool, Melton
Wool, Oxford
Rayon
Rayon, Taffeta.

Two-inch square specimens of each of the above were dried for one hour in an oven at 100°C and then cooled in a dessicator containing a drying agent. Each specimen was then weighed and placed in a dessicator over distilled water at room temperature (i.e. in an atmosphere of 100% RH). At various intervals of time the specimens were removed from the dessicator, weighed and replaced. The percentage change in weight of each was calculated. Results are presented in Table III. Figure 6 is a graph of change in weight versus time for representative specimens.

The above procedure was repeated several times and at various conditions of relative humidity. Figure 7 shows the percentage change in weight versus time of one specimen of Hudson Bay Wool for several of the replications. This material is similar in appearance to that of the wool freize sock used in CF mukluks. The results shown are typical of each of the samples investigated.

From the above experiments it was concluded that, (a) the samples investigated did not reach moisture equilibrium with the atmosphere to which they were exposed within the time frame proposed for wearing trials (less than six hours), (b) results were not reproduceable.

It was decided that, although the "wool swatch" method might be of use if it was investigated and developed further, this technique was not suitable for the current investigations. Other techniques for measuring relative humidity inside the mukluks were not attempted.

TABLE III

Change in Weight Versus Time of Samples of Textile Materials

Sample I.D.	Percentage Change in Weight as a Function of Time (hours)						
	1	2	3	4½	26	45	140
Wool, Hudson Bay	6.9	10.3	11.9	12.6	24.1	28.5	34.0
Wool, Serge	6.8	9.0	10.7	11.7	19.5	22.2	26.0
Cloth, Melton, DRB	6.1	9.4	11.0	11.9	21.0	25.1	28.7
Wool, Melton	4.9	7.8	9.5	10.1	18.8	21.2	25.4
Wool, Oxford	5.2	8.0	10.0	10.9	18.7	20.9	24.6
Rayon	1.4	1.9	3.0	3.9	9.1	10.5	12.3
Rayon, Taffeta	0.8	2.5	3.2	3.5	8.2	10.0	11.0

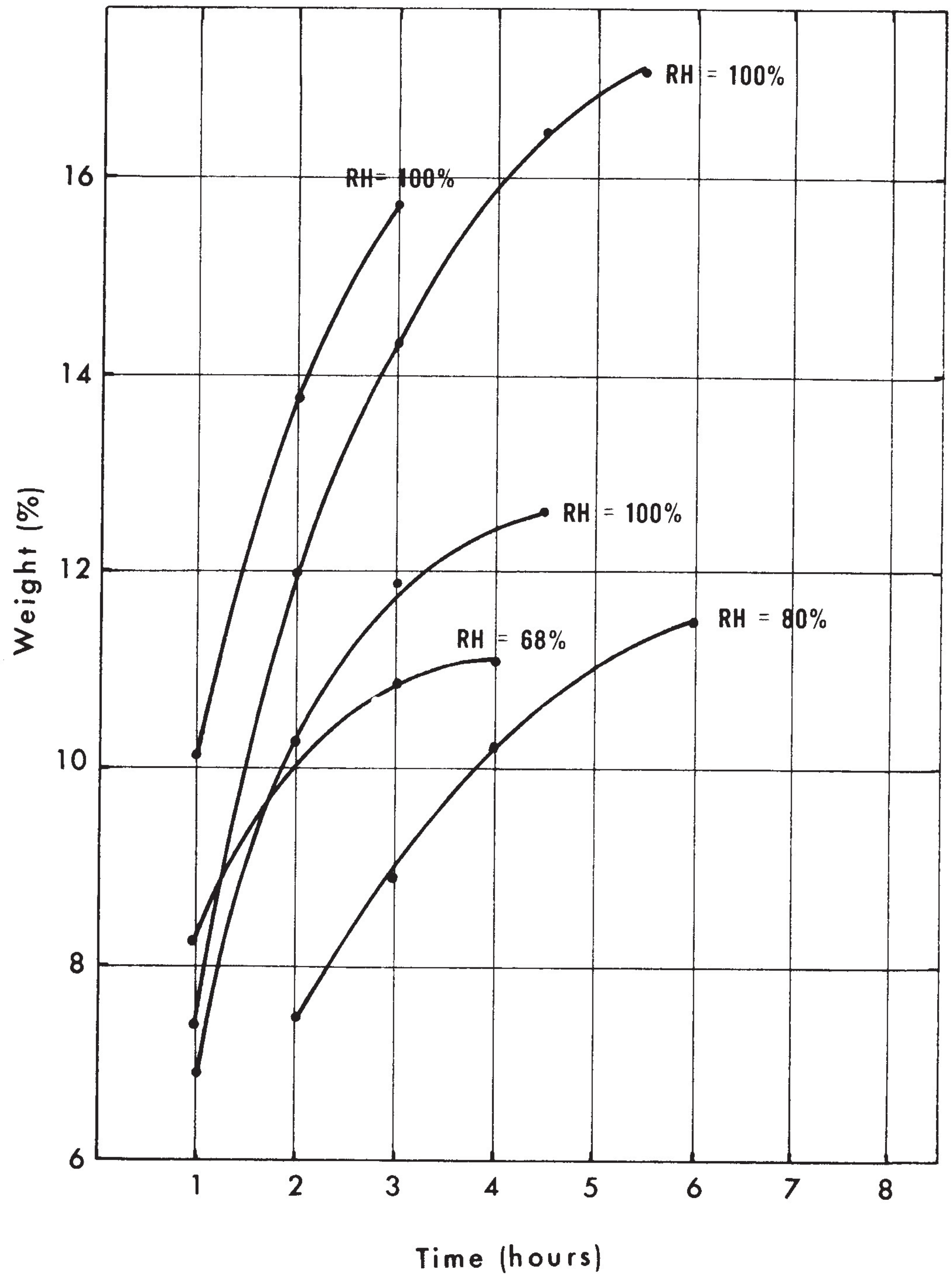

Fig. 6 Variation in Results: Test Using One Sample of Hudson Bay Wool

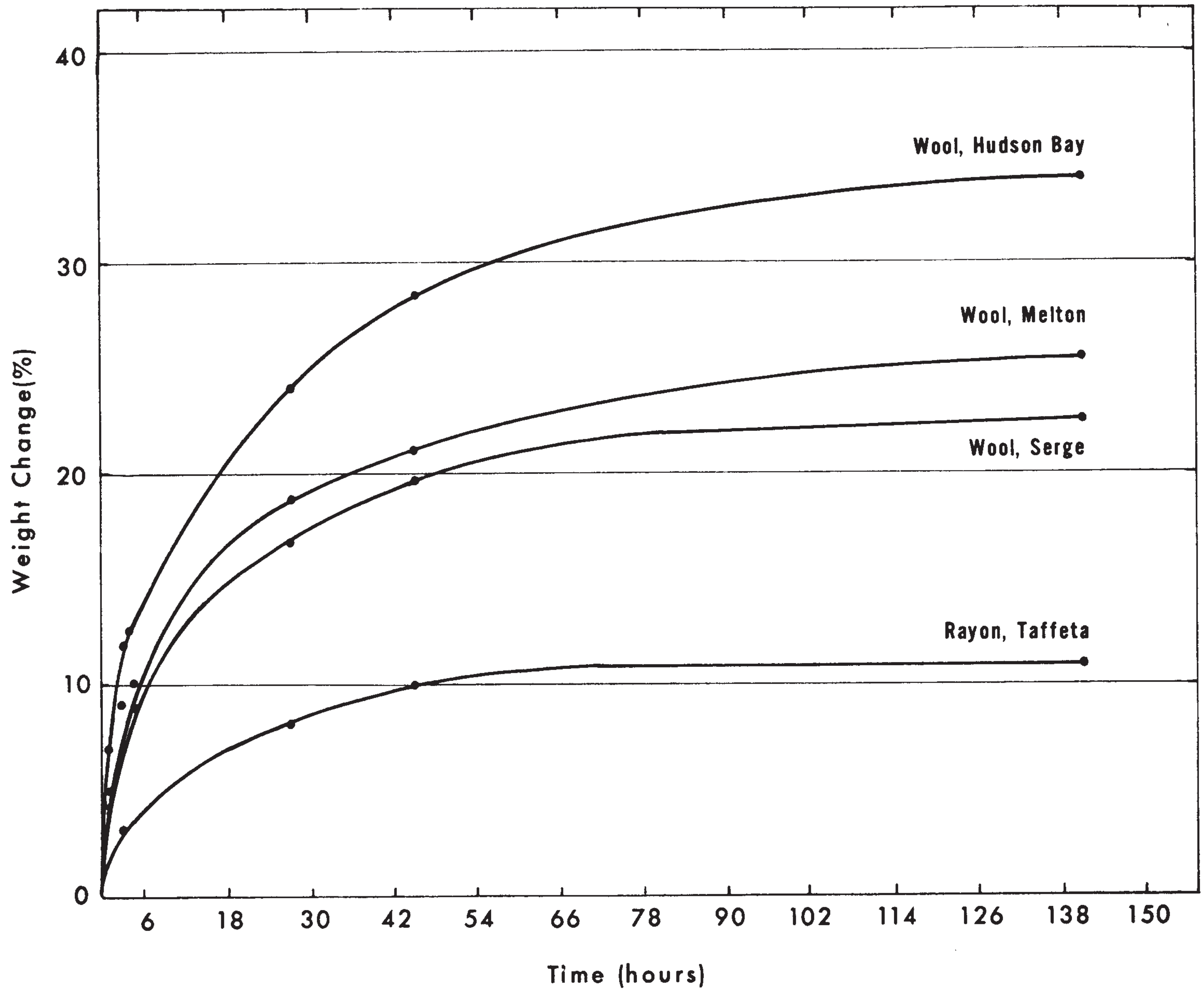

Fig. 7 Weight Change as a Function of Time of Wool Swatches (RH=100%)

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13. ABSTRACT

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A series of laboratory and field trials was conducted to compare standard permeable CF mukluks and experimental impermeable mukluks with respect to comfort, moisture accumulation due to foot perspiration and techniques for use. It was found that if properly dried overnight, there was little difference between the two types of mukluk. However, it was shown that conditions inside a tent in the field in winter are such that drying is very difficult and moisture accumulation over an extended period of time may cause significant problems with either type of footwear. No subjective differences between permeable and impermeable mukluks were observed.

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KEY WORDS

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Cold Weather Footwear

Arctic Clothing

Cold Weather Tests

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