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PROTECTIVE CLOTHING BASED ON PERMSELECTIVE MEMBRANE AND CARBON ADSORPTION

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DISCLAIMER

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4.8 Protective Clothing Based on Permselective Membrane and Carbon Adsorption

CONTRACT INFORMATION

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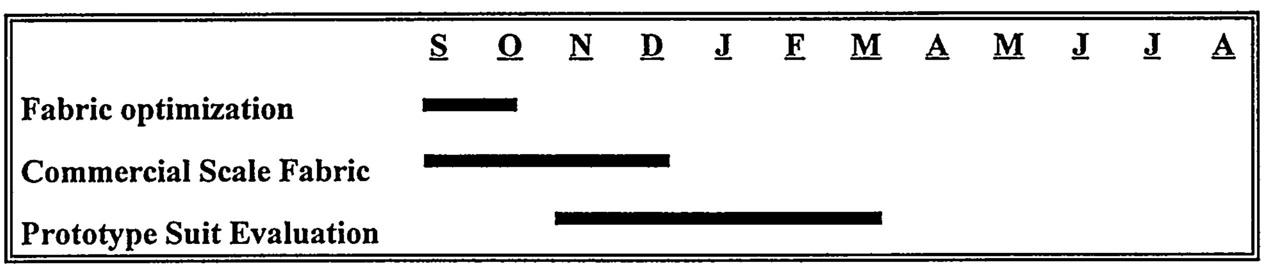
Schedule and Milestones

FY95 Program Schedule



OBJECTIVES

The objective of the program is to develop improved protective clothing for use by workers engaged in decommissioning and decontamination of former Department of Energy sites, including those used for atomic weapons research and production. Such sites are contaminated with a variety of hazardous compounds, ranging from asbestos, mercury and other heavy metals, to toxic organic compounds, such as PCB and chlorinated solvents, and radioactive metals and salts. Because of the hazards of exposure to these materials, workers must wear protective garments. These garments, which are made from Saran®, butyl rubber or other impermeable materials, provide excellent protection against particulates, liquids, aerosols, organic vapors and gases, but are impermeable to water vapor. Consequently, humidity and temperature within the suit rise rapidly during use, causing increasing discomfort. Heat stress occurs if the suit is worn for more than brief periods without resting.

The proposed technology concerns a new protective clothing fabric that combines a permselective membrane layer with a sorptive layer. If successfully developed, suits made from this fabric will offer equivalent, or better, protection than current materials, combined with a very high water vapor transmission rate (1,000 $g/m^2 \cdot day$ or more) that will dramatically improve "breathability," comfort, and worker productivity.

BACKGROUND INFORMATION

Over the next three decades, the Department of Energy faces an enormous decontamination and decommissioning task as facilities associated with research, development, and production of atomic weapons are closed. This task is complex and expensive because most sites are contaminated with a variety of hazardous compounds which range from asbestos, mercury and other heavy metals, to toxic organic compounds, such as PCB and chlorinated solvents, and radioactive metals and salts. Because of the hazards of exposure to these materials, workers must wear protective garments. These garments are impermeable to particulates, aerosols, and organic vapors and provide good protection from toxic contaminants. However, the garments are heavy, time consuming to don and remove, and most importantly, are impermeable to water vapor. Since the garments are water vapor impermeable, it is very difficult for body heat to escape. As a result, workers easily become heat stressed and must rest frequently.

These frequent rests can significantly reduce worker productivity. The Heat Stress Limits recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) are useful to demonstrate the productivity to be gained by a water vapor permeable suit (see Figure 1)[1]. Using this figure and making several assumptions (wet bulb globe temperature, WBGT, of 22°C; MTR suit performs like a winter work uniform whereas conventional protective clothing performs like a water barrier), the MTR water permeable suit will allow a 25% increase in productive time — a substantial increase.

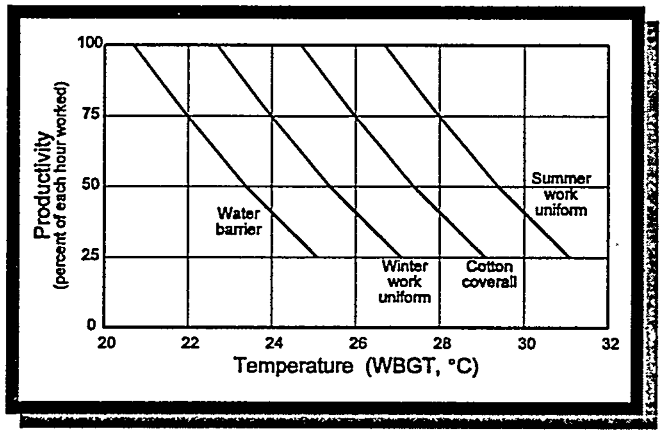


Figure 1. Heat Stress Limits Recommended by ACGIH

PROJECT DESCRIPTION

Membrane Technology and Research, Inc. (MTR) has been developing improved protective clothing that provides protection equivalent to that of current suits, but is water vapor permeable to minimize heat stress, and lighter weight for improved wearer comfort. The innovative feature of our improved fabric (see Figure 2) is an ultrathin, permselective outer membrane that is extremely permeable to water but impermeable to toxic organic compounds. The membrane layer protects the body from all particulate and liquid hazards and gives extended protection against organic vapors. To add a supplementary level of

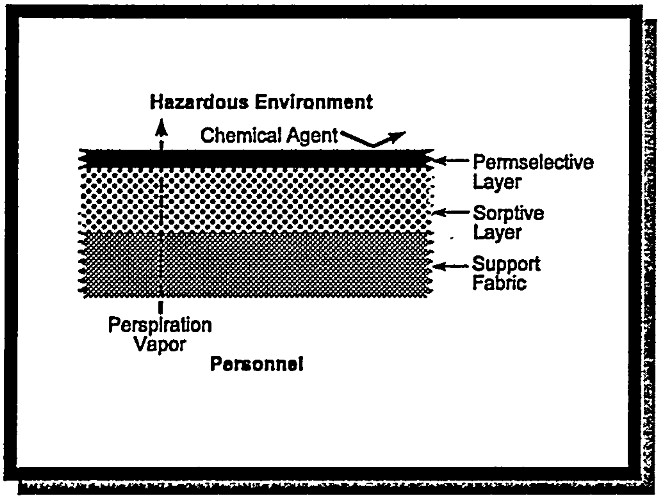


Figure 2. Protective Clothing Concept.

protection, the fabric has a sorptive layer, consisting of a porous membrane containing dispersed adsorbent. This layer increases the protective capacity against organic liquids and vapors and acts as a backup barrier in case the outer membrane is breached by abrasion or wear. The membrane layers are coated onto a conventional nylon fabric that provides mechanical strength. The water vapor transmission rate through the fabric is 600-950 g/m^2•day, compared to protective impermeable butyl rubber suits with transmission rates of 0-10 g/m^2•day, and non-protective porous Tyvek® suits with a transmission rate of 500-1,000 g/m^2•day.

This project is a 3-year, two-phase program to complete development of the fabric and to demonstrate its utility in field trials at the DOE Oak Ridge or Fernald sites. In the first 20-month phase of the program, the fabric properties, particularly the chemical resistance, water vapor transmission rate, durability, and flexibility, will be improved by modifying the materials used to form the membrane and the preparation procedure. Production of the fabric will then be scaled up to use commercial-scale production machinery. A small number of prototype suits will be made and a preliminary suit evaluation conducted. In Phase II, 300-400 suits will be produced for a complete laboratory and field demonstration program.

RESULTS

The Phase I project has three major objectives: fabric optimization, commercial-scale fabric production, and prototype suit evaluation. The fabric has been optimized, and we are currently scaling up production to commercial scale. Once we have produced the commercial-scale fabric, it will be manufactured into suits for testing. The following sections describe our results to date on fabric optimization and commercial-scale fabric production.

Fabric Optimization

Fabric optimization involves optimization of the individual layers included in the final protective fabric, and optimization of the way these layers are combined. Table 1 shows the materials studied during the fabric optimization process. The layers include the support fabric, the sorbent layer (including the sorbent used, the polymer used, and the ratio of the two), and the permselective layer (including the polymer and post-treatment methods). We also studied the geometry used to combine the individual layers into the final protective fabric.

Support Fabric. We examined a number of materials, both woven and non-woven, for use as the support fabric; eventually we chose a woven, rip-stop nylon. The woven fabric has superior flexibility and durability than the non-wovens, although it is more expensive. The rip-stop nylon was chosen because of its strength and light weight (1 oz/yd).

Table 1. Parameters and Materials Studied During Fabric Optimization

Support Fabric	Polymer (in sorptive layer)	Sorbent	Permselective Layer	Geometry
Woven	Pellethane (PU)	0 to 63%	1-10 μm	four
polyester (3)	2103-55D	0-25 g/m²		
nylon (5)	2103-80AEF	Carbon	9 polymer grades	
Non-woven	2103-90AEF	Calgon Carbon Co.		
polyester (2)	Estane (PU)	PCB-G, WPH, WPL	post treatments	
nylon	2714-F5P	Norit		
polypropylene	Kynar (PVDF)	SA Plus		
	721	Elf Atochem		
	741	Acticarbone 2S		
	761	Acticarbone ENO		
	2801	PAC 200		
	2851	Zeolite		
		UOP s-115		
		UOP Smellrite		
		Zeochem 13X		

Sorbent Layer. For the polymer used in the sorptive layer, we examined several grades of two different polymers: polyvinylidene fluoride (PVDF) and polyurethane (PU). (In earlier studies polysulfone was also examined but was ruled out due to stiffness.) PVDF has excellent chemical resistance[1], but only moderate flexibility, and low durability. PU, on the other hand, is very flexible and durable, but has only moderate chemical resistance. Based on these considerations, we chose PU as the polymer used in the sorbent layer.

For the sorbent we chose a zeolite, after studying various types of activated carbons and zeolites. The activated carbons are less expensive, have a higher capacity for organic compounds, and adsorb compounds over a wider range of molecular weights than do zeolites. However, these advantages are outweighed by the fact that fabrics containing carbon are black, an undesirable color to wearers of protective clothing, whereas fabrics containing zeolite are white. Organic compound permeation and water transmission tests showed no significant difference between the performance of fabrics made with carbon or zeolite.

The sorbent content and thickness of the sorbent layer are also important to the overall performance of the final protective fabric. We examined sorbent layers with sorbent contents between 0 and 63% (by weight) and determined 50% to be a good choice. Higher sorbent content diminishes durability, while lower content reduces the quantity of sorbent available and reduces water vapor transmission through the sorbent layer.

The sorbent layer thickness (~ 5 mils) was chosen to make the layer as thin as possible (to increase flexibility and reduce weight), while ensuring that the layer is consistent and smooth.

[1] Chemical resistance refers to physical or chemical degradation of the polymer due to contact with a particular chemical compound, not to resistance to permeation of a compound through the polymer. The polymer used in the sorbent layer, which is microporous, does not need to have high permeation resistance because it is meant only to support the sorbent, not to prevent passage of permeating compounds.

The selected thickness and sorbent content result in a sorbent loading of ~ 50g/m².

Permselective Layer. Several polymers were studied for use as the permselective layer. One particular polymer was chosen for its combination of organic permeation resistance, chemical resistance, water transmission, and ease of use. A thickness of ~ 5-10 μm was chosen; a thinner layer resulted in defects in the permselective layer, while a thicker layer reduced the rate of water transmission unacceptably.

A variety of post-treatment methods were used to improve the permselective polymer's resistance to permeation by organic compounds. Figure 3 shows that post-treatment reduces the organic permeation rate by more than 95%.

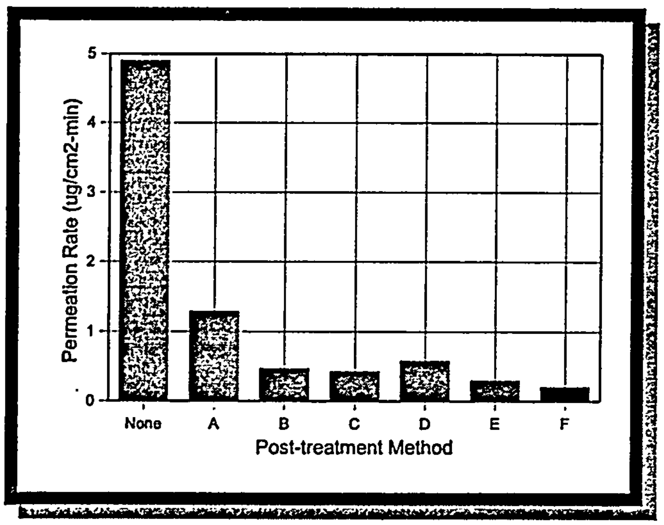


Figure 3. Permselective Layer Post-Treatment Results

Geometry. The optimum geometry is essentially that shown in Figure 2. In order from the inside (next to the wearer) to the outside (contacting the hazardous environment) are the support fabric, the sorbent layer, the permselective layer, and (not included in Figure 2) an outer protective layer.

Performance of Optimized Fabric. The performance of the optimized fabric is shown in Table 2. The organic permeation resistance of our fabric (using dichloromethane as the permeating compound) just meets our performance goal. The water vapor transmission rate exceeds our goal. Flexibility and durability will not be evaluated until we have produced the commercial-scale fabric rolls.

Commercial-Scale Fabric Production

Commercial-scale fabric production includes scaling up from the 12-inch-wide machines used during fabric optimization to 40-inch-wide machines, and producing at least three to five rolls of 40-inch-wide fabric at least 100 m long.

Scaling up from the small to large machines required a number of trial runs to ensure that the chosen fabric will run smoothly through our machines with even tension across the fabric, and that the solution used to cast the sorbent layer does not bleed through the membrane.

Modifications made during scale-up include adding new rollers to keep the tension

Table 2. Performance Goals and Results

Property	Goal	Optimized Fabric	Commercial-Scale Fabric
Chemical permeation resistance (μg/cm²·min)	< 30	~ 30	?
Water vapor transmission (g/m²·day)	> 800	> 1000	?

even and prevent wrinkle formation, adjusting the casting solution viscosity and casting conditions to prevent bleed-through, and having the support fabric re-cut to eliminate the fabric edges from snagging in the machines. We expect to produce the commercial runs of fabric in November.

Prototype Suit Evaluation

The prototype suits have not yet been made, but we have begun to evaluate the economics of our breathable fabric.

To evaluate the economic viability of the MTR fabric, we considered two prices. The first, called the "selling price," is the price that we can afford to sell the fabric for, including all direct (materials, labor, etc.) and indirect costs (capital charges, overhead, profit, etc.); the second, called the "paying price," is the price that a user is willing to pay for a suit made from this fabric. For our fabric to be economically viable, our selling price must be less than the price the user is willing to pay. To estimate the selling price, we considered three cases. Case 1 assumes that we will produce 10,000 m^2 of fabric (~ 2,000 completed suits) per year using the equipment we now have (with minor modifications). Case 2 assumes that we will make 250,000 m^2 of fabric (~ 50,000 completed suits) per year with completely new facilities. Case 3 also assumes manufacture of 250,000 m^2 of fabric per year, but with a fabric recipe optimized to reduce raw material requirements.

Table 3 shows the total fabric selling price: \$14.38, \$6.52, and \$4.80 per square yard for cases 1, 2, and 3 respectively. The prices are high compared with those of other protective fabrics. Barricade, a highly protective fabric manufactured by Dupont, sells for approximately \$3.50/yd², Saranex-coated Tyvek sells for approximately \$1.20/yd², and Tyvek sells for less than \$1.00/yd². However, our fabric offers the advantage of the greater worker comfort and productivity achievable with a sweatable fabric. Using the estimated MTR fabric prices, the selling prices for suits made from this fabric would be \$110, \$63, and \$53 for cases 1, 2, and 3, respectively. (For comparison, suits made from Saranex-coated Tyvek and Barricade can be purchased for \$31 and \$45 respectively.)

Table 3. MTR Fabric Selling Price

	Fabric Selling Price ($/m²)		
	Case 1	Case 2	Case 3
Capital Costs[1]	3.50	2.80	2.80
Material Cost	5.99	3.77	1.70
Labor Costs	7.71	1.23	1.23
TOTAL $/m²	17.20	7.80	5.74
($/yd²)	(14.38)	(6.52)	(4.80)

[1] Including depreciation, taxes, ROI
Equipment costs: Case 1: \$30,000 (2 yr payback)
Case 2: \$800,000 (4 yr payback)

We also estimated the paying price for a suit made from MTR fabric. Because the MTR suit allows a worker to actually work a greater fraction of an 8-hour day (because fewer rest breaks are needed than a worker using a conventional protective suit), the employer should be willing to pay more for the MTR suit than for a conventional suit. Assuming that a worker wearing a conventional suit requires one hour more rest than a worker using the MTR suit, the extra that the employer should be willing to pay for the MTR suit is the cost for one hour of work. This cost includes direct labor costs (the worker's wages) and indirect costs (benefits, supervision, and the cost of equipment used by workers). We estimate a worker's direct wages to be \$15/hour and the indirect costs to be about the same amount, for a total cost of \$30/hour. Thus, an employer should be willing to pay about \$61 for a suit made from the MTR fabric: $31 (price for a conventional suit) plus $30 in extra productivity. This result suggests that the MTR suit would be economically competitive if it could be manufactured (and sold) on a large scale (~50,000 suits per year).

FUTURE WORK

Our next step is to demonstrate our suits at the laboratory prototype level. This includes producing several 100-m-long rolls of 40-inch-wide fabric, having it made into suits, and demonstrating in the laboratory that the suits are durable and reduce heat stress compared to conventional protective clothing.

If the suits show promise during laboratory evaluation, we will go on to Phase II of the project. In Phase II we will manufacture 300 to 400 suits and perform head-to-head field trials versus the clothing currently used at the field site. If the field trials demonstrate that the suits made from MTR fabric increase productivity, maintain good protection, and are durable, we will, with our manufacturing partner, begin commercial marketing and production of protective clothing made with the MTR fabric.

REFERENCES

1. American Conference of Governmental Industrial Hygienists, "1994-1995 Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices," ACGIH, Cincinnati, OH (1994).