Dec. 6, 1966 D. C. JENNINGS 3,289,748

HEAT TRANSFER GARMENT

Filed Sept. 4, 1964 3 Sheets-Sheet 1

FIG. 7

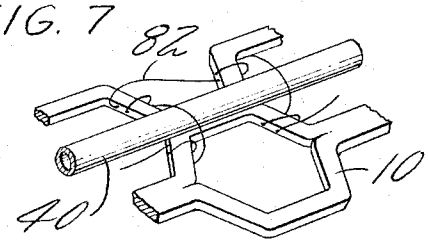


FIG. 1

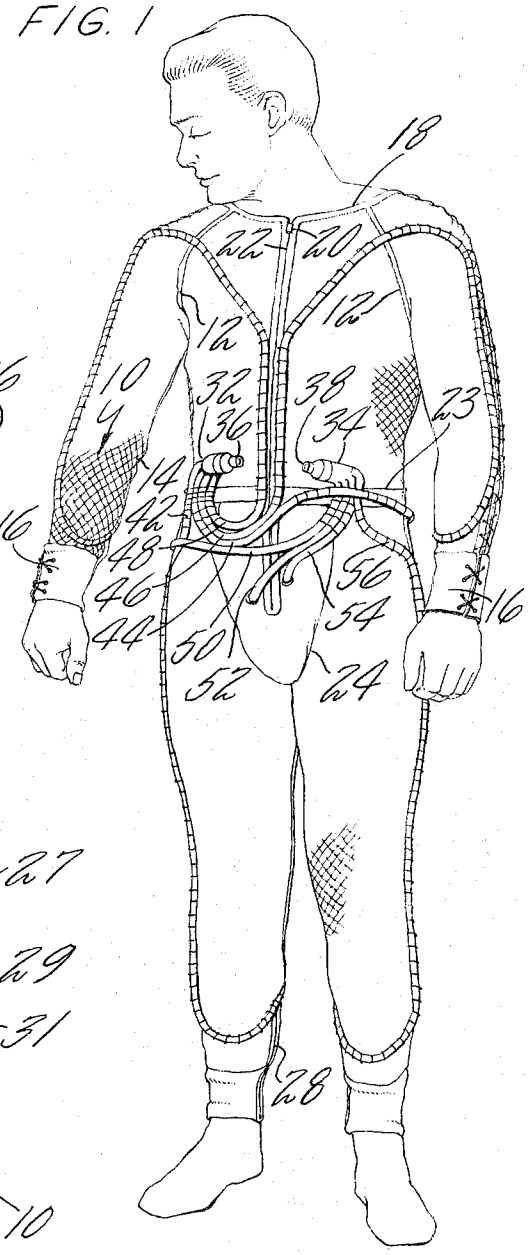


FIG. 2

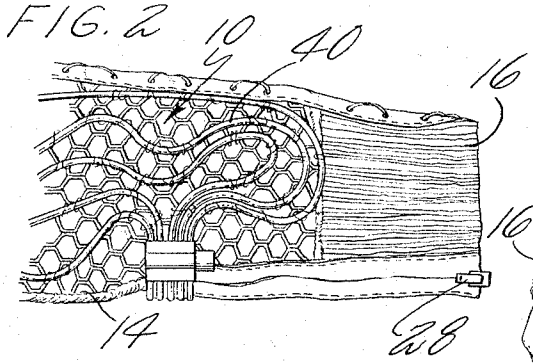


FIG. 3

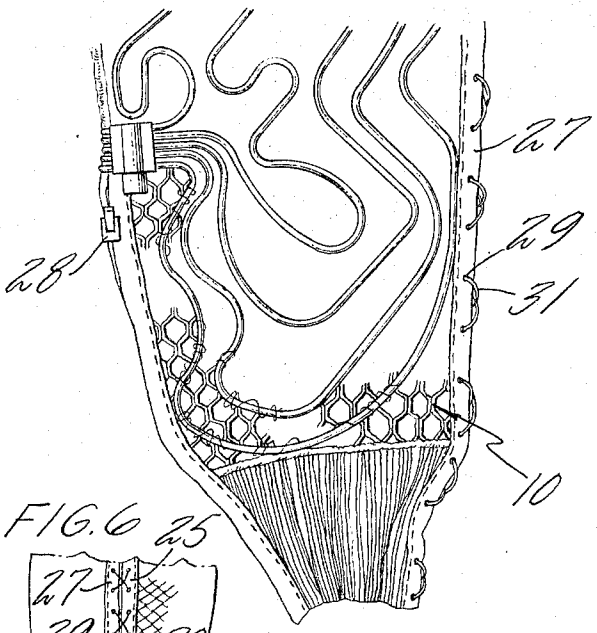
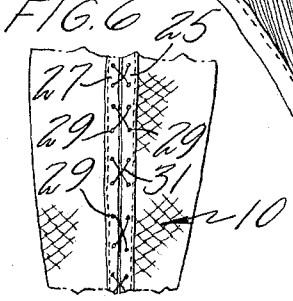


FIG. 6



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HEAT TRANSFER GARMENT

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FIG. 4

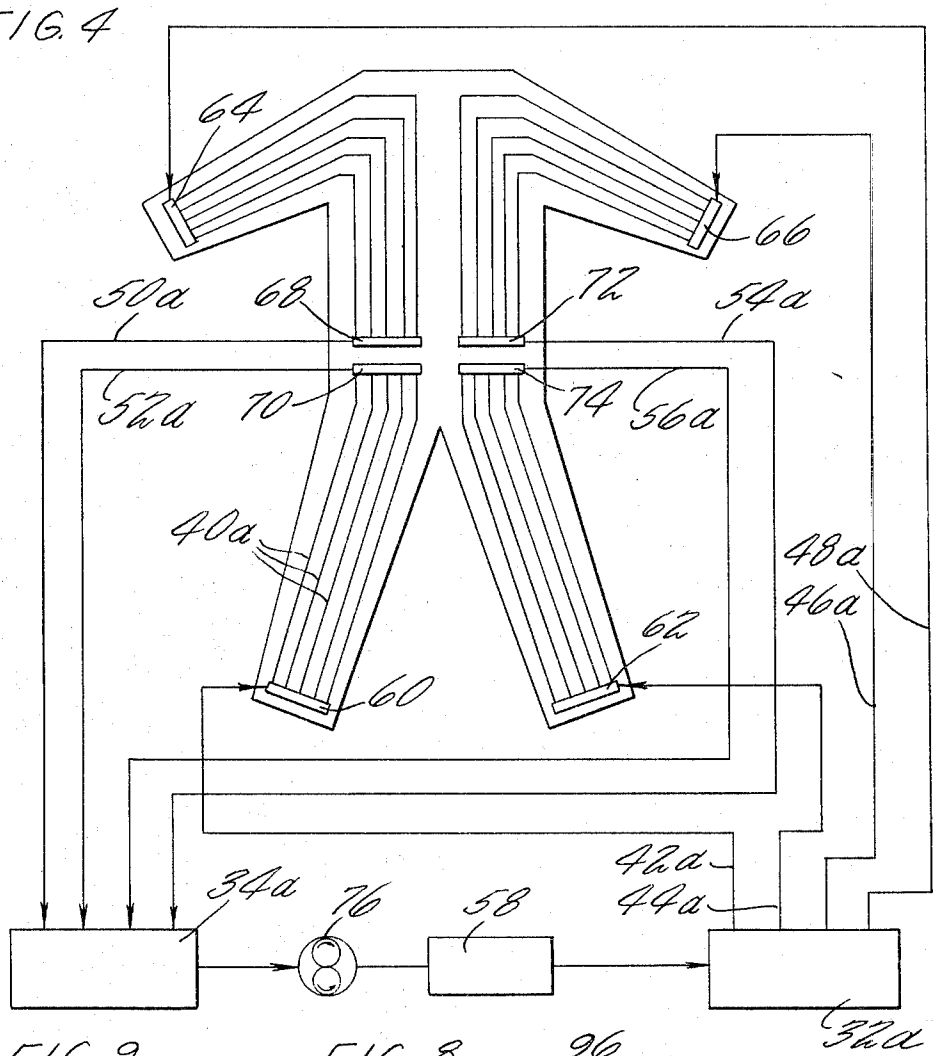


FIG. 9

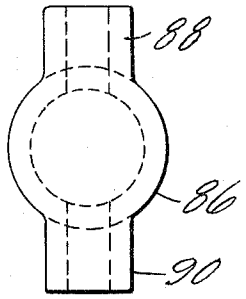
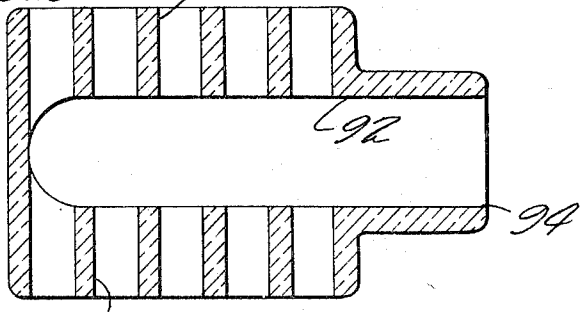


FIG. 8



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HEAT TRANSFER GARMENT

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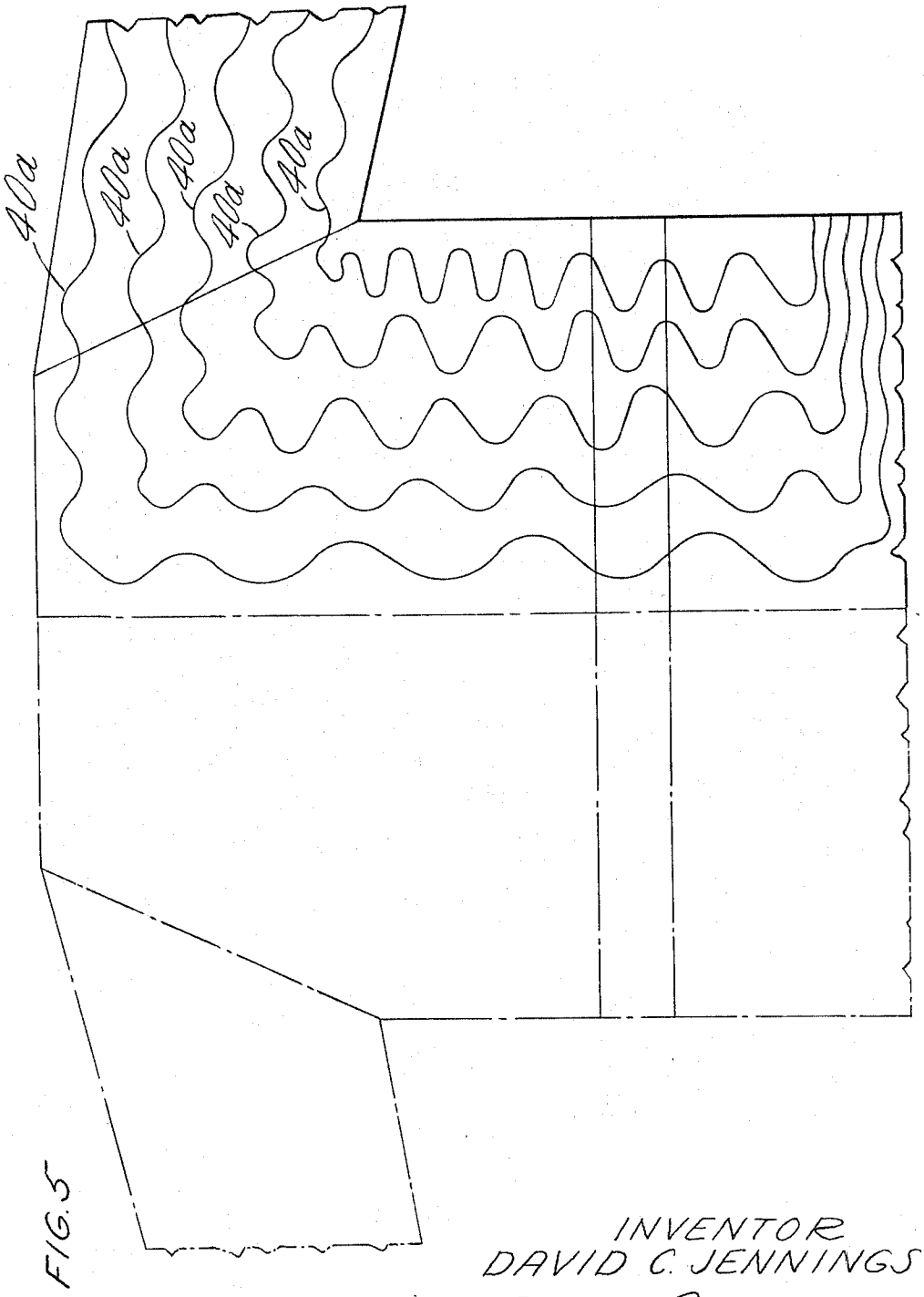

FIG. 5

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3,289,748
HEAT TRANSFER GARMENT

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Filed Sept. 4, 1964, Ser. No. 394,548
13 Claims. (Cl. 165—46)

This invention relates to liquid heat transfer garments and particularly to the construction of a liquid-cooled undergarment. The invention described herein was made in the performance of work under a NASA contract and is subject to the provisions of Section 305 of the National Aeronautics and Space Act of 1958, Public Law 85–568 (72 Stat. 435; 42 U.S.C. 2457).

It is an object of this invention to provide an undergarment including flexible liquid cooling conduits mounted on a net fabric in such a fashion as to be in contact with the skin of the wearer so as to cool the body by direct conduction of heat in an efficient manner.

A still further object of this invention is to distribute the tubing in the garment so that it covers the body of the wearer in approximate proportion to the local body mass, thereby providing heat removal capacity commensurate with metabolic heat generation capability.

A still further object of this invention is the mounting of the flexible tubing to an undergarment structure so that the tubing is distributed in serpentine or meandering paths within parallel routes of widths adjusted to fit a predetermined length for each tube within a given region of the undergarment.

A still further object of this invention is to provide in a garment as described, connecting means such as manifold fittings formed of material compatible with the material used in the cooling tubes so that the two are positively bonded or cemented together.

A still further object of this invention is to provide in an undergarment as described, a predetermined pattern for connecting the tubing into the manifold at predescribed locations in the undergarment to assure flexibility and convenience for the user.

A still further object of this invention is to provide in an undergarment as described, an arrangement of zippers and the like located at the torso front, the wrists and the ankles to provide ease of donning and doffing yet maintaining snugness of fit to the wearer.

A still further object of this invention is to provide a novel undergarment construction to permit adjustment to the individual wearer so as to assure snugness of fit to the proper degree by providing lacings along the sides of the front and back torso portion, sides of the legs, sides of the arms and over the shoulder.

A still further object of this invention is to provide in an undergarment as described, supply and return flexible tubes which are mounted in such a fashion on the front or anterior so as to permit and facilitate donning and doffing of the garment while avoiding having the tubes cross the garment back or posterior so as to assure comfort to the wearer as well as providing a route for these tubes for improved mobility.

A still further object of this invention is to provide in an undergarment as described, a waistband formed from elastic material attached to the net fabric in such a manner as to maintain snugness of fit at the waist of the wearer.

A still further object of this invention is to construct an undergarment with a net fabric material and orienting the material so that it is at approximately a 45° angle to the axis of the garment so as to obtain a two-axis stretch, a strong base for attachment of tube retaining

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stitches and yet capable of providing effective ventilation when cooling liquid is unavailable.

A still further object of this invention is to provide means for attaching the tubing to the structure so as to obtain a secured unit while avoiding loss of garment flexibility and stretch.

A still further object of this invention is to provide in a garment as described, tubes located in such a pattern so as to exclude straight runs of appreciable lengths to prevent tubes from migrating away from their original position and avoid the formation of kinks and pinching of the tubes.

A still further object of this invention is to provide tubes having a wall thickness that bears a predetermined dimension with respect to its inner diameter so as to avoid kinking and pinching off of the liquid stream in the tubes which may result from the operating loads and flexing.

A still further object is to provide in a garment as described, a basic structure formed from a net fabric material which allows the cooling of the wearer's body by gaseous ventilation when cooling liquid is not available.

Other features and advantages will be apparent from the specification and claims and from the accompanying drawings which illustrate an embodiment of the invention.

FIG. 1 is an anterior view of the garment as donned by the wearer illustrating this invention.

FIG. 2 is a view showing the cuff and lower sleeve of the garment.

FIG. 3 is a view showing the lower leg and cuff of the garment.

FIG. 4 is a schematic view illustrating the path of the various tubes and their connections.

FIG. 5 is a schematic view showing an arrangement of tubes in the upper right region of the torso.

FIG. 6 is a side elevation of a portion of the leg illustrating the lacing arrangement.

FIG. 7 is a schematic view illustrating the attachment of the flexible tubing to the net fabric.

FIG. 8 is a detailed sectional view of the manifold connector.

FIG. 9 is an end view of the manifold connector shown in FIG. 8.

Referring now more particularly to FIG. 1 which shows the anterior portion of the suit mounted on a wearer which is basically formed from a suitable net fabric generally indicated by numeral **10**. The limbs and the torso are formed in two sections, front and rear, and are suitably sewn together and laced together in such a fashion as to provide snugness of fit to the wearer as will become apparent from the following description.

Looking at FIG. 1, the major portion of the garment is formed from a suitable net fabric which preferably is a fishnet fabric or a Norwegian fabric which is available under the tradename of "Brynje." The fabric is made from a cotton yarn which is braided into an open mesh netlike structure interwoven at the intersections rather than being knotted as is generally the method in a net material used in fishnets. This construction forms a relatively flat surface and eliminates bulges which are formed from a knotted or over or underlapping type of net construction. I have found that a mesh size of 7/16 inch square pattern forms a satisfactory garment. Of course, other sizes may be equally suitable for this purpose.

As noted from FIG. 1, the arms are joined to the upper torso portion of the net fabric at the shoulder along seams **12** by any suitable means such as sewing. The back and front part of the arms are sewn together on the inner side indicated by seams **14**. The outer side of the arms including the top portion of the shoulder, are provided with a tape sewn to the end of the net material having a series

of eyelets for accommodating lacings so as to permit the wearer to tighten the garment and adjust it to snugly hug the contours of the limbs. At the wrist, suitable cuffs **16** may be provided and are suitably joined to the net.

The front of the undergarment is formed from a single sheet of net fabric to flex to hug the body contours of the wearer. The posterior is likewise formed from a single sheet of net fabric and cut to conform to the body of the wearer. The two are laced together at the sides of the torso and outsides of the legs by a lacing extending from the foot to a point on the sleeve slightly beyond the armpit. A tape **18** is sewn at the neck to help support the sleeves. A front opening **20** is provided and extends down a substantial length of the front of the torso and may carry suitable joining means such as zipper **22**. Band **23** made from suitable elasticized material is sewn on the inner surface of the net material and extends across the front waist to the sides of the garment. A similar material is similarly mounted on the inner surface of the posterior waist section of the net fabric and also extends to the side edges.

From the foregoing, it is apparent that the garment is adjusted to snugly fit the wearer. This is accomplished by first donning the garment by opening the zippers. Once donned, the wearer would adjust the laces until the garment snugly fits his body. After the proper fit is obtained, he can then unfasten the garment and doff it while retaining proper fit.

As noted from FIG. 6, the sides of the anterior and posterior of the garment carry tapes **25** and **27** having a series of holes or eyelets **29** extending vertically for accommodating lacing **31** so as to allow the wearer to easily adjust the garment to fit the contours of his body. The left and right sides of the anterior and posterior of the garment are constructed in this manner. Since the net material has a two-way stretch, snugness of fit is assured.

For comfort of the wearer, a fabric covering **24** may be fitted around the crotch and lower front and rear portion of the torso. This fabric may be sewn to the garment in any suitable manner.

The garment, as noted above, provides cuffs made from a suitable knit material at the wrist and at the angle of the wearer which cuffs are sewn or suitably joined to the net fabric.

snugness of fit provided by the cuff, it is necessary for the wearer to unfasten the cuff zippers to don and doff the garment.

In accordance with this invention, suitable ducting or flexible conduits are mounted on the inner surface of the garment in a predetermined manner as to be described hereinbelow. It can be seen, however, from FIG. 1 the supply line and return line are mounted on the anterior portion of the garment. A proper or suitable manifold **32** which, for description purposes, may be considered to be the supply manifold and manifold **34** which may be considered to be the return manifold, extend and project on the outside of the garment above the waist. Suitable tubing (not shown) connects with the inlet tube connection **36** of manifold **32** and outlet tube connection **38** of manifold **34** for supplying and returning cooling transport fluid, such as water, through the tubes in the garment.

It is contemplated within the scope of this invention that a plurality of tubes made from a suitable material such as polyvinylchloride are distributed in a serpentine or meandering pattern so that the distribution of tubing over the body is in approximate proportion to local body mass, thereby providing heat removal capacity commensurate with metabolic heat generation capability. Thus, in its preferred form, the tube length distribution should be made proportional to body mass distribution so as to provide local cooling capacity approximately equivalent to local heat generation capability. While an actual calculation of the mass of the human body may be calculated, such a calculation is extremely difficult and for the purpose of designing the garment it is only necessary to make certain assumptions as to the volume of the human body. The following chart giving the tube distribution calculation from body mass distribution is prepared with the assumption that the body can be represented by adjoining cylinders making up an average man as having the following dimensions: legs, 30 inches high and 5 inches in diameter; arms, 30 inches high and 3 inches in diameter; upper torso, 18 inches high and 11 inches in diameter; lower torso, 10 inches high and 11 inches in diameter; and head, 11 inches high and 7 inches in diameter. Of course, it is to be noted that the particular size of the suit and the tube distribution will vary according to the particular size of the man for whom the suit is designed.

	Volume (in.³)	Weight (lb.)	Area (ft.²)	Volume fraction	Area fraction	Height (in.)	Distributed Head Volume and Area			
							Volume fraction	Area fraction	Tube length (in.)	Tube length fraction
Head	423	15.3	1.68	.090	.088	11	0	0	0	0
Rt. arm	212	7.6	1.96	.045	.104		.049	.114	15.4	.052
Lt. arm	122	7.6	1.96	.045	.104					
Rt. upper torso	855	30.8	2.16	.182	.115	18	.201	.126	58.6	.198
Lt. upper torso	855	30.8	2.16	.182	.115					
Sub Total				.544	.526		.250	.240	74.0	.250
Rt. lower torso	475	17.1	1.20	.102	.064	10	.111	.070	33.4	.113
Lt. lower torso	475	17.1	1.20	.102	.064					
Rt. leg	589	21.2	3.27	.126	.173	30	.139	.190	40.6	.137
Lt. leg	589	21.2	3.27	.126	.173					
Sub Total				.456	.474		.250	.260	74.0	.250
Total	4,685	168.8	18.85	1.000	1.000	69				

Another feature of this invention is that zippers **28** sewn on the side of the ankle cuffs **30** and mounted on the side of the wrist cuffs are provided to further assure proper snugness of fit. As noted in FIGS. 2 and 3 (showing the inner surface of the garment), the eyelets for the laces are located opposite the respective zippers and extend from the edges of the cuffs to the neck of the wearer in the case of the sleeves and extend from the lower edge of the ankle cuff to the armpits on the front and rear sections. The cuffs are so constructed that when the zippers are fastened, garment rise is limited. Owing to this

Once the mass distribution of the body is calculated and the number and lengths of tubes selected, the cooling tubes are then generally laid out in patterns which may follow the 45° slope of the net strands as referred to the axis of the garment. In this way the ability of the garment to stretch along either longitudinal or transverse axis with body displacement is not impaired. As can be seen in FIG. 5, which is the upper right region of the torso, five tubes schematically illustrated in a typical pattern by numeral **40***a* are made of equal length to form a pattern in serpentine or meandering paths with parallel

routes of widths adjusted to fit within this region of the garment. Obviously, the other limbs and torso regions of the garment are formed in a similar manner to assure that the heat conductivity is proportional to the heat generation throughout the entire body. Hence, in each region of the body the tubes have equal lengths and are similarly secured to the net fabric in a serpentine pattern.

As noted from FIG. 1 the supply manifold **32** distributes liquid to four conduits **42, 44, 46** and **48** and the return manifold **34** receives the discharging liquid from four conduits **50, 52, 54** and **56** for passing liquid through the tubes mounted on the interior of the open netted fabric which, in turn, dissipates the heat generated by the wearer. The distribution of fluid is best seen by referring to schematic shown in FIG. 4.

Referring now particularly to FIG. 4, it can be seen that the liquid cooled by any suitable means, such as heat exchanger **58**, is directed to manifold **32*a*** (all subscripted reference numerals correspond to the elements referenced in FIG. 1) for distributing the cooled liquid to conduits **42*a*, 44*a*, 46*a*** and **48*a*** to be, in turn, distributed to the plurality of tubes **40*a*** sewn to the inner surface of the net fabric via the respective connecting manifolds **60, 62, 64** and **66**. The transport liquid picking up body heat by conduction in passing through the tubes **40** is then returned to the inlet of the pump by a network of return tubes **50*a*, 52*a*, 54*a*** and **56*a*** via return manifolds **68, 70, 72** and **74**.

Although the flow of transport liquid may be controlled by a suitable fluid pump schematically shown by numeral **76**, it should be understood that any other means for regulating the flow of the transport liquid is contemplated within the scope of this invention. As for example, where available, the liquid may be taken from an ordinary cold water tap.

From the foregoing, it is apparent that all the return manifolds are located at the waist of the wearer and the supply manifolds located at the distal portion of the limbs. While this is the preferred arrangement of the manifolds, it is to be understood that other arrangements are within the scope of this invention.

In fabrication of the garment tubing **40** is fastened to the net by stitching while the net is distended over a flat form having dimensions corresponding to body semi-circumferences.

It is noted that the net fabric forming the basic garment structure is set at approximately 45° angle to the axis of the garment for the combined purpose of obtaining a two axis stretch, a strong base for the attachment of tube retaining stitches, and compatibility with the requirements for ventilation when the coolant liquid supply is unavailable.

The tubes are secured to the net fabric so that they form close coupled bends, meanders or serpentine undulations without straight runs of appreciable length for the purpose of avoiding the working of tubes through the stitches which would result in the accumulation of excessive lengths of tubes at the few sharp bends and promote the formation of kinks and tube pinching as well as reducing garment flexibility and cooling efficiency.

The tubes are attached by making a tack stitch through the net cross strand twice on each side of the tube with the doubled thread crossing over the tube. This method of stitching does not loosen when a thread is cut. Preferably, the thread travels slackly from one cross strand to the next to avoid compressing the net.

This is best illustrated by referring to FIG. 7. Tube **40** is attached by two tack stitches through an adjacent cross strand of net **10** on one side of the tube with thread **82** crossing over the tube. Two more tack stitches are made on the adjacent cross strand of net **10** on the other side of the tube. The thread at this point is pulled taut to firmly retain the tube. Then the thread is loosely laid until it reaches the adjacent point of attachment.

In the illustrated garment cooling tubes **40** are of 1/8 inch outside diameter by 1/16 inch inside diameter polyvinylchloride, each 74 inches long and ten started at each wrist and ankle. Hence, a total of 40 tubes of 427 feet of actual length which makes contact with the skin. The supply and return tubes **42, 44, 46, 48, 50, 52, 54** and **56** are of 3/16 inch inside diameter by 5/16 inch outside diameter polyvinylchloride. It will be appreciated that the walls of the tubes are relatively thick as compared to their diameters for the purpose of reducing danger of kinking and pinching off of the coolant stream as the result of operating loads and flexing. For this purpose the thickness of the wall should be at least 25 percent of the diameter of the tube.

The supply and return tubes are mounted in such a manner so as not to interfere with the wearer's mobility. As seen in FIG. 1 the supply and return tubes are loosely mounted at the front torso zipper for ease of donning and doffing and avoiding crossing the garment back for comfort, and following a route across the front of the shoulder for improved mobility.

After the tubes are mounted they are inserted into the proper manifolds and then cemented into place. The tubes and manifolds are preferably made from the same material in order to assure positive bonding.

The preferable manifolds are fabricated according to the type shown in FIGS. 8 and 9. Manifold **84** may be molded into a single piece having a central generally circular shaped body section **86** with opposing projecting sections **88** and **90**. The molded body contains a centrally extending opening **92** communicating with inlet **94** which communicates with a plurality of radially extending openings **96** which, in turn, are adapted to receive the ends of the proper tubes.

What has been shown by this invention is an undergarment construction carrying a plurality of cooling tubes on the inner surface of a net fabric and in intimate contact with the skin of the wearer for dissipating heat in an efficient manner. The use of the net fabric as the basic supporting structure affords flexibility for assuring snugness of fit to the wearer, permitting ventilation in the event of unavailability of cooling liquid, and is lightweight so as to be comfortable on the wearer. The particular two-piece construction and side lacings allow the wearer to readily adjust the garment to enhance the snugness of fit. The flexibility of fabric and method of adjustment assure that the garment will snugly hug the contour of the body of the wearer so that the tubes will always be in intimate contact with the skin of the wearer. By the particular tubing and pattern thereof, the possibility of formation of kinks and tube pinching is reduced while providing garment flexibility and cooling efficiency. It is to be understood that this garment may be worn with or without an overgarment.

It should be understood that the invention is not limited to the particular embodiments shown and described herein, but that various changes and modifications may be made without departing from the spirit or scope of this novel concept as defined by the following claims.

I claim:

1. A garment enclosing the body of the wearer, said garment having a plurality of heat transfer tubes supported in contact with the wearer's body, means for conducting fluid through said tubes for transporting heat to or from the wearer's body, a fabric supporting the tubes, the number of tubes adjacent a given area being dictated by the mass adjacent that area so that the lesser mass has the lesser number of tubes whereby the heat transfer effect of the tubes for any area of the body is substantially proportional to the local mass of the body adjacent that area.

2. A garment as claimed in claim **1** wherein said fabric is made from a yarn intertwined into a netlike cloth having spaces communicating the skin of the wearer to the adjacent atmosphere.

3. A garment as claimed in claim 1 wherein the tubes are made from polyvinylchloride.

4. A garment as claimed in claim 1 wherein the thickness of the walls of said tubes is at least equal to 25 percent of the diameter of the tube.

5. A garment as claimed in claim 1 wherein the tubes in a given region of the garment are of substantially equal length.

6. A garment enclosing and cooling the body of the wearer including a plurality of equally sized cooling tubes adapted to conduct a cooling fluid for conducting heat away from the body of the wearer distributed in serpentine or meandering paths within parallel routes of widths within a predetermined length for each tube in a predetermined region of the garment, said tubes being supported in contact with the wearer's body, a flexible fabric supporting the tubes, and the number of said tubes adjacent a given area of said body being determined by the mass of the body adjacent that area so that the lesser mass has the lesser number of tubes.

7. A garment as claimed in claim 6 wherein said fabric is formed in an anterior section and a posterior section, and adjustment means adjacent the sides of said sections for urging said sections toward each other so that said fabric distorts to snugly fit the contours of the body of the wearer whereby said tubes are held in intimate contact therewith.

8. A garment enclosing and cooling the body including the torso and limbs of the wearer, including a plurality of cooling tubes supported in contact with the wearer's body, a fabric supporting the tubes, the number of tubes adjacent a given area of said body being determined by the mass of that body area so that the lesser mass has the lesser number of tubes, said fabric formed into an anterior section and a posterior section each extending to the outer sides of the torso and limbs, means including lacings extending along the sides of the legs, sides of the arms, sides of the torso for securing said anterior section to said posterior section whereby the garment is adjustable to snugly fit the contour of the body of the wearer.

9. A garment as claimed in claim 8 including a first band formed from a flexible material secured on the inner surface of said anterior section adjacent the waist and a second band formed from a flexible material secured on the inner surface of said posterior section adjacent the waist.

10. A garment enclosing and cooling the body of the wearer, including a plurality of cooling tubes supported in contact with the wearer's body, a fabric supporting the tubes, said fabric formed by interlocking threads defining strands arranged in an open mesh joined at spaced intervals, said strands of said fabric being oriented at approximately 45° angle with respect to the axis of the garment so as to be flexible in two axes and said tubes being arranged to substantially follow the 45° slope of said strands.

11. A garment as defined in claim 10 wherein said tubes are arranged so that the cooling effect of the tubes for any area of the body is substantially proportional to the local mass of the body adjacent that area so that the lesser mass has the lesser number of tubes adjacent thereto.

12. A garment as defined in claim 11 wherein said garment includes predetermined regions of the body, and said tubes being distributed in serpentine or meandering paths within parallel routes of widths adjusted to fit a predetermined length for each tube within each of said regions.

13. A garment enclosing and cooling the body of the wearer, including a plurality of cooling tubes supported in contact with the wearer's body, a fabric supporting the tubes, the tubes being arranged such that the cooling effect of the tubes for any area of the body is substantially proportional to the local mass of the body adjacent that area so that the lesser mass has the lesser number of tubes, a supply of cooling liquid, connection means to and from said supply including a plurality of conduits mounted on the outer surface of said garment, and fastening means on the front center portion of said garment, said tubes extending over but spaced from said fastening means permitting accessibility thereto.

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