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(54) **HEAT CONDUCTIVE TEXTILE AND METHOD PRODUCING THEREOF**

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Related U.S. Application Data

(63) Continuation-in-part of application No. 11/306,529, filed on Dec. 30, 2005. Continuation-in-part of application No. 11/306,530, filed on Dec. 30, 2005. Continuation-in-part of application No. 11/307,051, filed on Jan. 20, 2006. Continuation-in-part of application No. 11/307,125, filed on Jan. 24, 2006. Continuation-in-part of application No. 11/307,292, filed on Jan. 31, 2006. Continuation-in-part of application No. 11/307,359, filed on Feb. 2, 2006. Continuation-in-part of application No. 11/306,527, filed on Dec. 30, 2005. Continuation-in-part of application No. 11/308,107, filed on Mar. 7, 2006.

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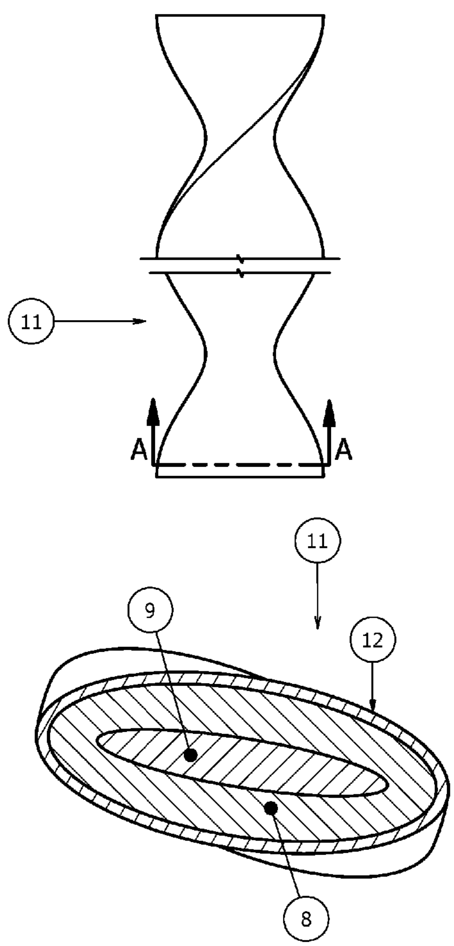
(57) **ABSTRACT**

Textile material **1** with phase changing liquid **2**/vapor **4** mix embedded through its sealed inner volumes **3.** Material **1** utilizes at least two types of yarn surfaces, one with high affinity to liquid **2** and another that repels liquid **2.**



SECTION A-A

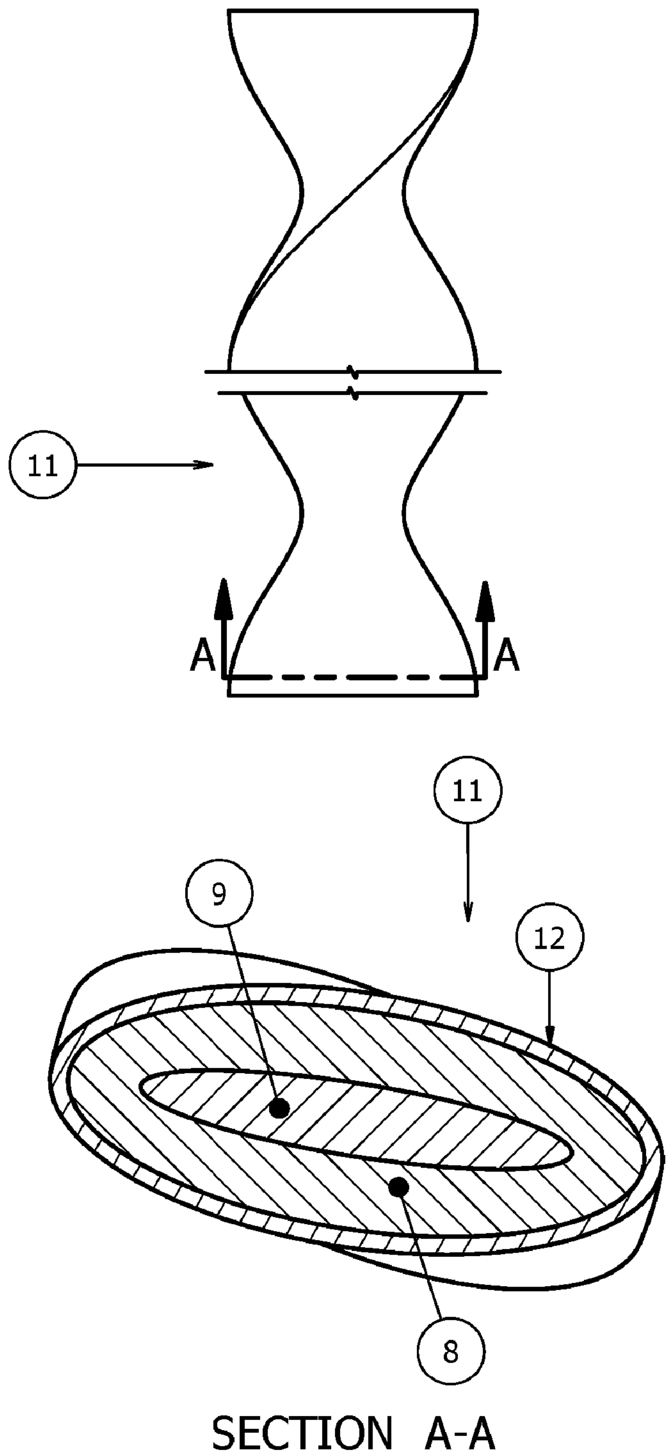
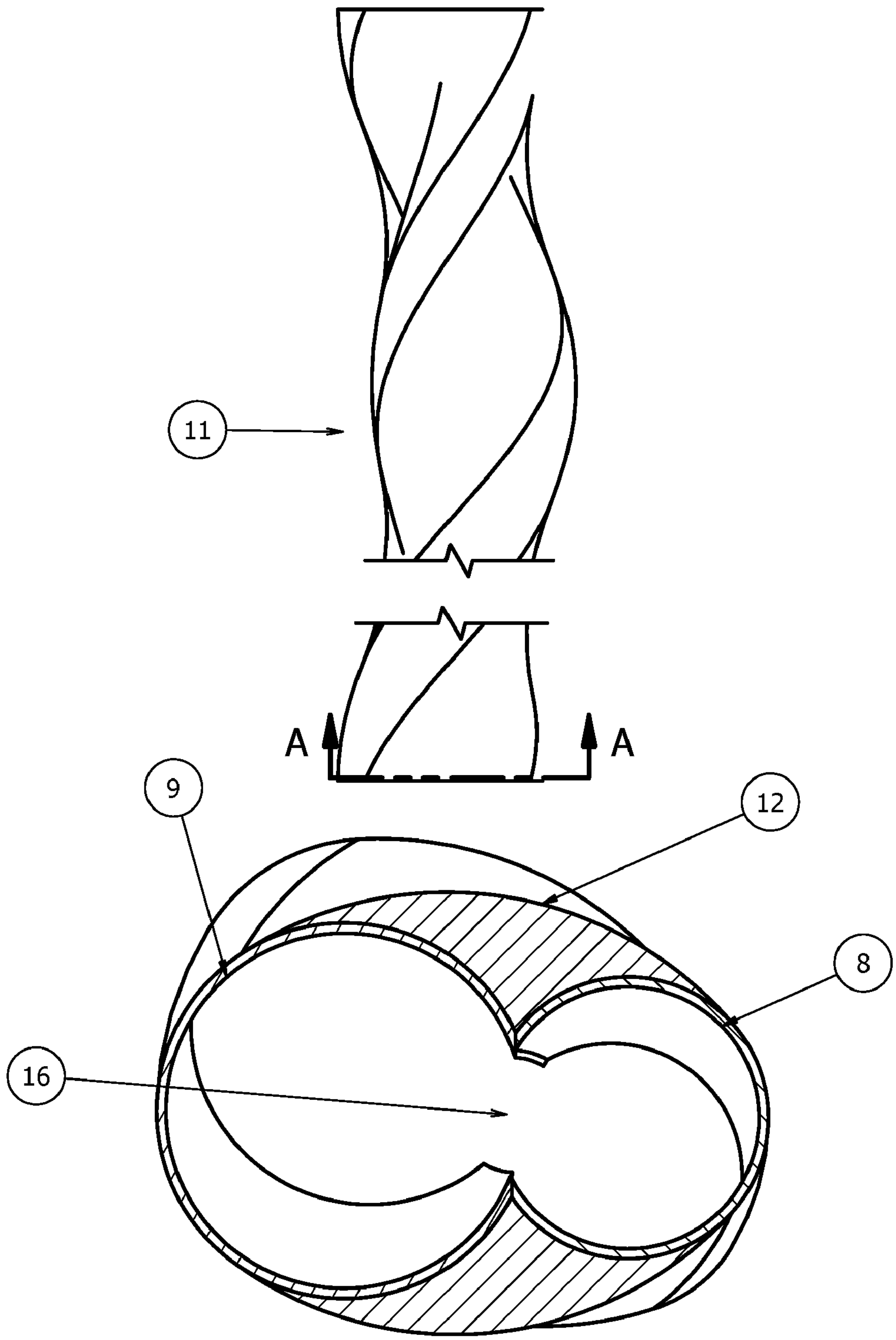


Figure 1



SECTION A-A

Figure 2

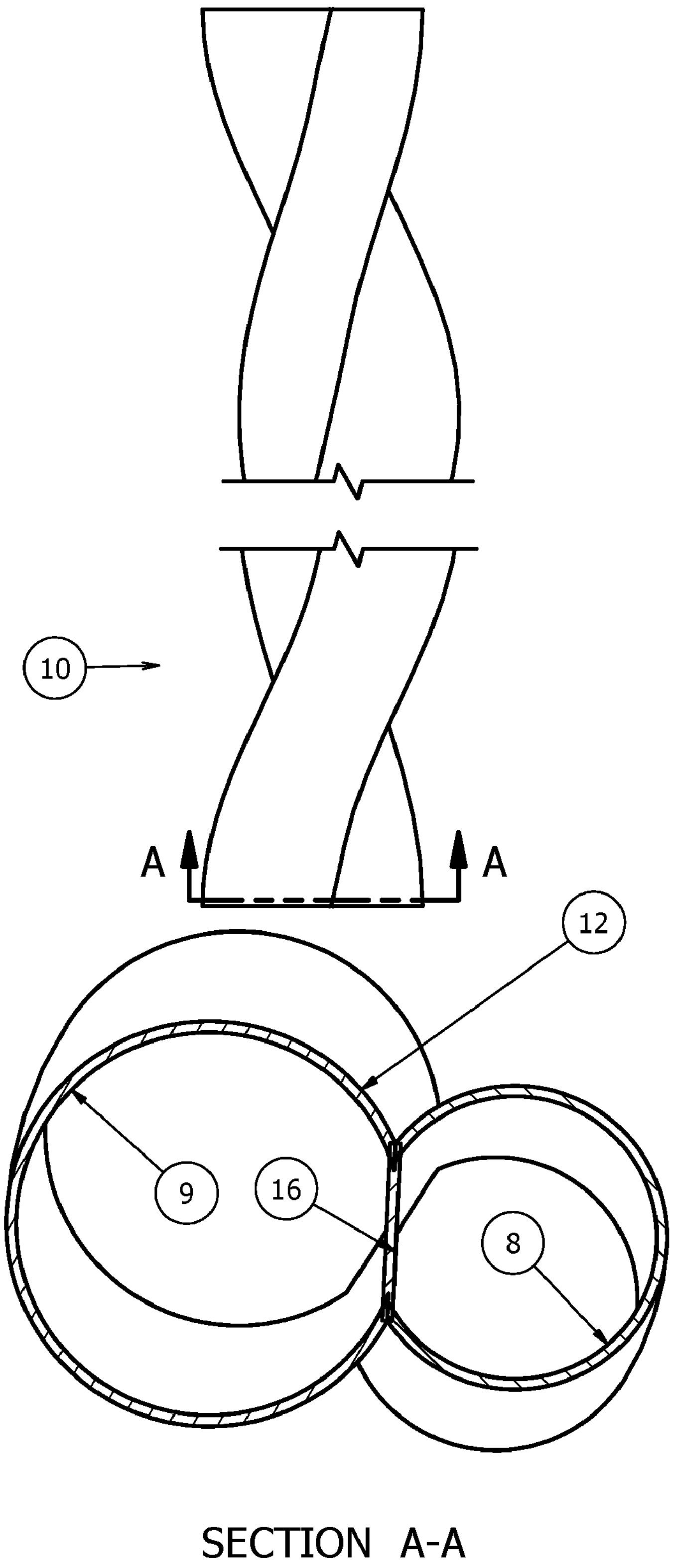
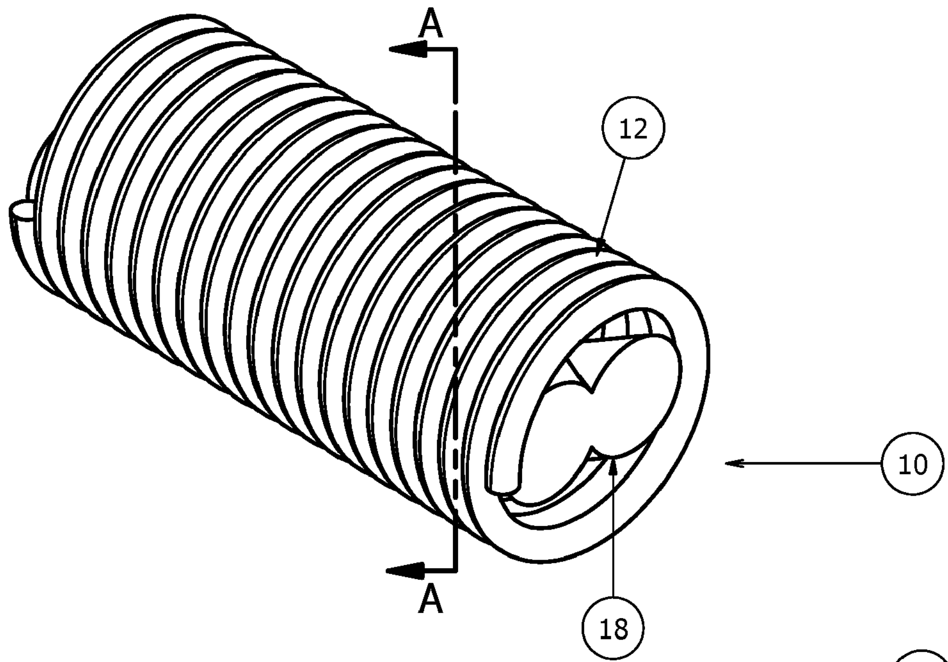
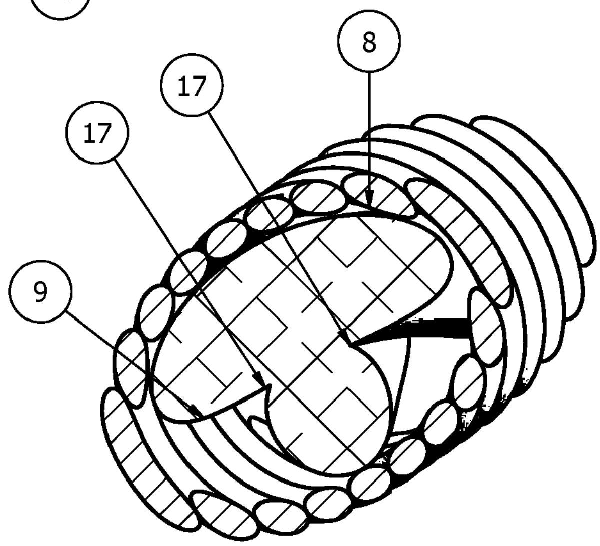


Figure 3





SECTION A-A

Figure 4

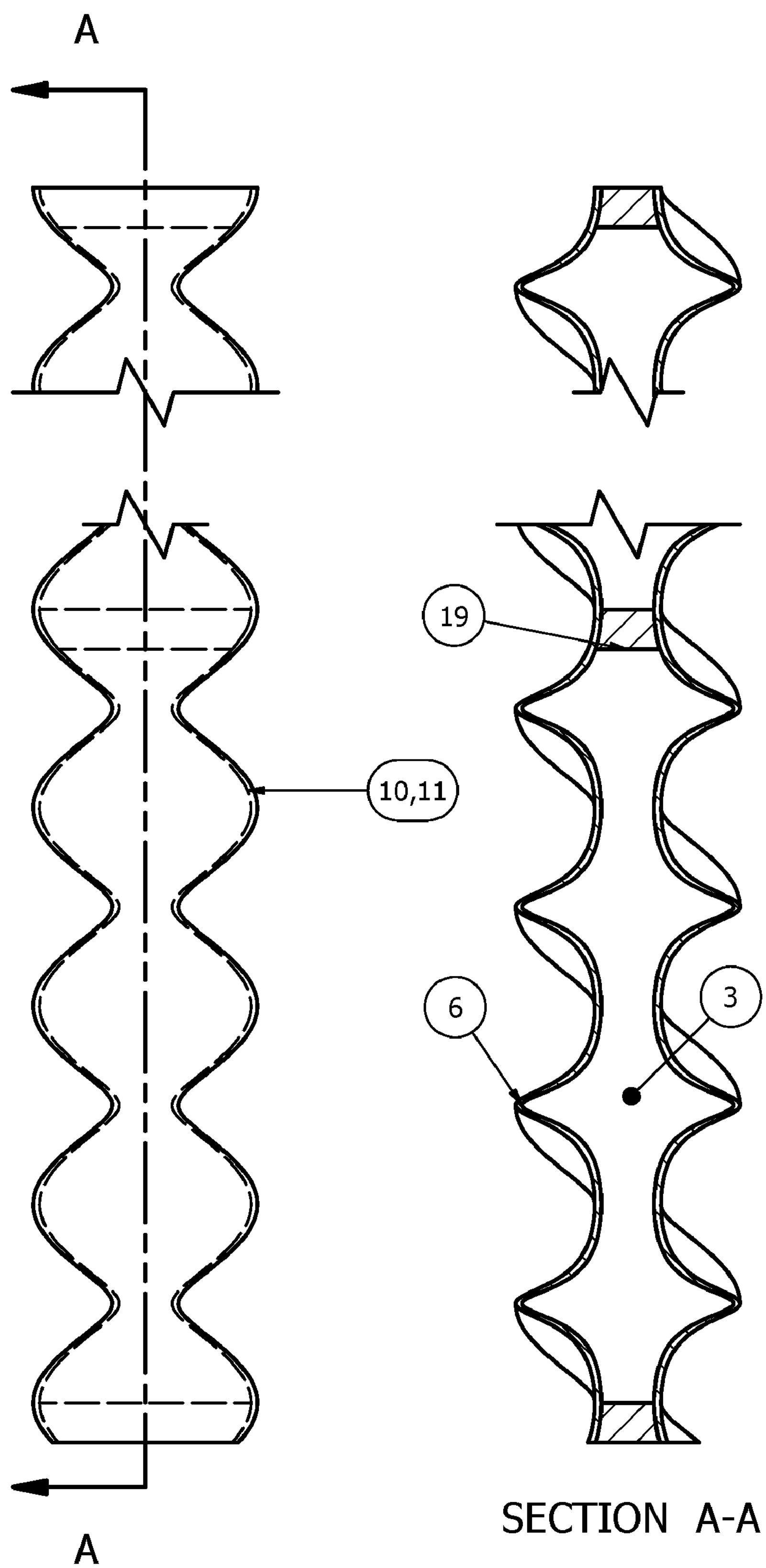


Figure 5

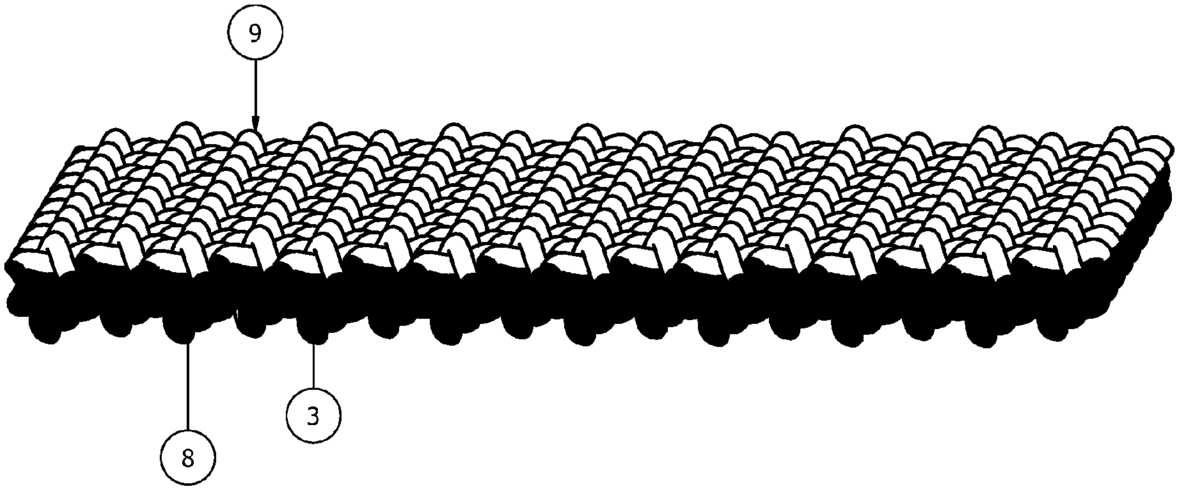


Figure 6

HEAT CONDUCTIVE TEXTILE AND METHOD PRODUCING THEREOF

RELATED APPLICATIONS

[0001] This application is a continuation-in-part of each of:

[0002] (1) U.S. patent application Ser. No.: 11/308107, filed Mar. 7, 2006, entitled "Tunable heat regulating textile", hereby incorporated by reference

[0003] (2) U.S. patent application Ser. No.: 11/307359, filed Feb. 2, 2006, entitled "Stretchable and transformable planar heat pipe for apparel and footwear, and production method thereof", hereby incorporated by reference

[0004] (3) U.S. patent application Ser. No. 11/307,292, filed Jan. 31, 2006, entitled "High throughput technology for heat pipe production", hereby incorporated by reference

[0005] (4) U.S. patent application Ser. No. 11/307,125, filed Jan. 24, 2006, entitled "Integral fastener heat pipe", hereby incorporated by reference

[0006] (5) U.S. patent application Ser. No.: 11/307,051, filed Jan. 20, 2006, entitled "Process of manufacturing of spongy heat pipes", hereby incorporated by reference

[0007] (6) U.S. patent application Ser. No. 11/306,530, filed Dec. 30, 2005, entitled "Heat pipes utilizing load bearing wicks", hereby incorporated by reference

[0008] (7) U.S. patent application Ser. No. 11/306,529, filed Dec. 30, 2005, entitled "Perforated heat pipes", hereby incorporated by reference

[0009] (8) U.S. patent application Ser. No. 11/306,527, filed Dec. 30, 2005, entitled "Heat pipes with self assembled compositions", hereby incorporated by reference

FIELD OF THE INVENTION

[0010] Present invention relates to advanced textile and fabrics incorporating special fibers, yarns, threads. These threads represent novel capillary heat pipes. The textiles of the invention are suitable for technical or apparel and footwear applications. In particular, materials for heat and cold protection and medical aids are directly related to the field of this invention.

BACKGROUND OF THE INVENTION

[0011] Known capillary heat pipes utilize principles disclosed by Akachi U.S. Pat. No. 4,921,041 (1990) and U.S. Pat. No. 5,219,020 (1993). These principles can be summarized as: (i) closed loop capillary profile; (ii) bubble-liquid train. While providing many benefits these principles has known drawbacks. Closed loop requires delicate steps in manufacturing process that maintain relatively high price tag for related products. Train of bubbles and liquid segments through the length of the capillary loop reduces heat exchange efficiency with capillary walls. In evaporating region only tiny amount of liquid surface is available as interface between liquid and vapor that makes evaporation less efficient. Overheat of liquid causes formation of new bubbles that causes notable acoustic and mechanical distortion. In condensing region only a portion of capillary executes high efficient heat exchange caused by direct condensation of vapors on capillary walls, the rest of capillary dumps heat through thermal conductivity of liquid which is by several orders of magnitude less efficient.

[0012] To address last of these problems Huang (U.S. Pat. No. 6,269,865) attempts to increase surface area of evaporating and condensing regions through addition of grid shaped capillary segments. This approach however adds gravitational bias to their invention, as its function requires initialization step when evaporator placed below condenser.

[0013] Another common disadvantage of loop and multi-loop capillary heat pipes utilizing bubble train is their intrinsic emission of mechanical vibrations. These vibrations affect longevity of thermal interfaces with stationary design members.

[0014] Present invention resolves these disadvantages by placing bodies of materials with radically opposite affinities to refrigerant liquid inside the volume of capillary. Such novel approach prevents formation of bubble train and creates adjacent channels for liquid and its vapors inside the same narrow capillary.

SUMMARY OF THE INVENTION

[0015] This invention utilizes concept of textile material **1** having phase changing liquid refrigerant composition **2** disposed within volume **3** of yarns, threads, sleeves, or any other topological arrangement comprising the structure of material **1**. Liquid **2** remains at balance with vapors **4** of constituent chemicals. Additional gaseous elements **5** may be added into the vapor mix. Elements **5** have lower boiling point than lowest intended usable temperature of material **1**.

[0016] Material **1** may contain plurality of partially interlacing domains **6**, wherein each domain **6** represents a confined volume **3** separate from volumes of adjacent domains **7**. Adjacent domains **7** may be of different types, wherein types collection include domains with enclosed volumes **3** and domains with other textile structures and properties hereinafter referred as traditional textile.

[0017] Volumes **3** comprise at least two distinct types of structural elements hereinafter referred as yarns. Essential distinction between the types of yarns is their affinity to liquid **2**. Yarns **8** have high affinity to liquid **2**, while yarns **9** have lower affinity to liquid **2**.

[0018] Yarns **8** and **9** may be braided to form spatial layout where at each location of yarns **8** there is a neighboring location of yarns **9**. This requirement can be fulfilled by knitting yarns **8** and **9** into fabric in a way that both yarn types are uniformly or otherwise distributed through the process. Alternatively both types of yarns can be priory braided to form a sleeve or other structure hereinafter referred as thread **10**. Thread **10** then can be incorporated into woven, knitted or other type of textiles.

DETAILED DESCRIPTION OF THE INVENTION

[0019] FIG. **1** depictures embodiment utilizing invented composite yarn structure **11**. Material of yarn **9** repels liquid **2** due to its intrinsic properties or due to appropriate surface treatment. This prevents liquid **2** from occupying volume of yarn **9**. Gases **5** may be incorporated into design and will occupy volume of yarn **9**. Material of yarn **8**, on opposite, has high affinity to liquid **2** due to its intrinsic properties or due to appropriate surface treatment. This results in liquid **2** occupying volume of yarn **8**. Yarn **11** is sealed from surrounding volume by shell **12**. Shell **12** is impermeable to vapors **4**.

[**0020**] When temperature of yarn **11** is below phase transition temperature **13** of liquid **2** at sustained pressure of gases **5** in volume of yarn **9** the only mechanism for heat transfer across yarn **11** is thermal conductivity of liquid **2**, and materials of yarns **8** and **9**. Thermal conductivity of yarn **9** is low as its volume occupied by non-condensing gases **5**.

[**0021**] When temperature of yarn **11** reaches phase transition temperature **13** of liquid **2** at sustained pressure of gases **5** in volume of yarn **9** vapors **4** migrate directly through volume of yarn **9** and condense on colder side of yarn **11**. Condensed liquid **2** than migrates back to hotter regions through the volume of yarn **8** by means of capillary forces. Heat transfer efficiency by condensing vapors **4** is by two orders of magnitude more efficient that passive heat transfer through heat conductivity of materials.

[**0022**] Textile material incorporating yarns **11** provides novel thermal management properties. At temperatures below certain setpoint temperature **13** material has low normal thermal conductivity **14**, at temperatures above setpoint **13** it turns into efficient heat conductor with normal heat conductivity **15** significantly higher than thermal conductivity **14**.

[**0023**] FIG. **1** depictures yarn **11** not in scale. Liquid **2**, vapors **4**, and gases **5** are not shown. Yarn **11** is shown as twisted although flat and other structures are equally allowable. Yarns **8** and **9** are shown as distinct elements although their structure may interlace forming complex patterns. Example of technologies suitable for production of such yarn structure was disclosed in co-pending patent applications Ser. Nos. 11/307,051, 11/307,292. Other traditional technologies of yarn production can be adapted in obvious manner to suite the same.

[**0024**] Broad range of liquids **2** and yarn materials **8**, **9**, **12** can suite the production. As one of examples, liquid **2** is decafluorobutane, gas **5** is nitrogen plus diffused air, yarn **8** is composed of polyethylene fibers, yarn **9** is composed of glass fibers or silica gel particles, and shell **12** is nylon.

[**0025**] FIG. **2** depictures structure of composite yarn **11** of the invention. Yarns **8** and **9** are represented by or imbedded into walls of circular cavities surface properties of these cavities correspond to surface properties of yarns **8** and **9** with respect to liquid **2**. Both cavities are enclosed by single shell **12**. Cavities are connected in the middle by narrow opening **16** (enlarged for visualization purpose).

[**0026**] Volume of cavity **8** is occupied by liquid **2**, and volume of cavity **9** is occupied by vapors **4** and optional gases **5**. Although cross section area of both cavities is extremely small, liquid **2** does not block cavity **9** due to repelling surface properties. This unique feature allows decoupling of lateral motions for vapors **4** and liquid **2**. Application of heat at some location along yarn **11** causes evaporation of liquid **2** through opening **16**. Because interface between liquid **2** and vapors **4** is constantly present along full length of yarn **8**, there is no additional energy involved in formation of such interface and accordingly there are no mechanical nor acoustic distortions produced.

[**0027**] Evaporated liquid **2** is replenished by lateral capillary transport along yarn **8**. Generated vapors **4** freely propagate to cooler locations along yarn **9** where they condense to form liquid **2** on interface **16**.

[**0028**] Gases **5** may be added into the design to provide setpoint temperature **13** if desired. Textile material incorporating yarns **11** depictured on FIG. **2** has high lateral thermal conductivity which allows spreading of localized heat fluxes through larger area. This property is extremely useful in applications such as extreme heat and fire protection as well as in performance fabric applications.

[**0029**] FIG. **2** shows yarn **11** not in scale. Liquid **2**, vapors **4**, and gases **5** are not shown. Yarn **11** is shown as twisted although flat and other structures are equally allowable. Yarns **8** and **9** are shown as circular tube elements although their structure may have any other form. Example of technologies suitable for production of such yarn structure was disclosed in co-pending patent applications Ser. Nos. 11/307,051, 11/307,292. Other traditional technologies of yarn production and polymer extrusion can be adapted in obvious manner to suite the same.

[**0030**] Broad range of liquids **2** and yarn materials **8**, **9**, **12** can suite the production. As one of examples, liquid **2** is decafluorobutane, gas **5** is diffused air, surface of yarn **8** is polyethylene fibers, surface of yarn **9** is composed of glass fibers, and shell **12** is nylon.

[**0031**] FIG. **3** depictures structure of thread **10** that is analogous to one of yarn **11** depictured on FIG. **2**. Design shown on FIG. **3** allows for larger diameter threads **10** suitable for technical and special purpose textile materials. Yarns **8** and **9** in this design are replaced by braided sleeves with corresponding properties of inner surfaces. These sleeves are either inter-braided to form integral profile shaped like digit eight, or simply twisted together. Outer surface of such assembly is sealed with compound **12** impermeable to vapors **4**. Interface **16** formed between channels **8** and **9** lacks any sealant and is permeable to vapors **4**.

[**0032**] Volume of channel **8** is filled with liquid **2**, while volume of channel **9** is dry and only contains vapors **4** and optional gases **5**. Interface **16** operates as a check valve allowing vapors **4** to travel from channel **8** to channel **9**, and liquid **2** from channel **9** to channel **8** but not in opposite directions. Application of heat to some locations along the length of thread **10** causes evaporation of liquid **2** from channel **8** and formation of vapors **4** in channel **9** without any bubbles. Vapors are then traverse to cooler location along channel **9** where they condense on interface **16** replenishing liquid **2** in channel **8**. All other aspects of operation of thread **10** are identical to those of yarn **11** shown on FIG. **2**.

[**0033**] FIG. **3** shows thread **10** not in scale. Sealant **12**, liquid **2**, vapors **4**, and gases **5** are not shown. Thread **10** is shown as twisted although flat and other structures are equally allowable. Channels **8** and **9** are shown as circular tube elements although their shape may have any other form. Example of technologies suitable for production of such yarn structure was disclosed in co-pending patent applications Ser. Nos. 11/307,051. Other traditional technologies of yarn and braided sleeves production and polymer extrusion can be adapted in obvious manner to suite the same.

[0034] FIG. **4** depictures another design of thread **10**. Unlike previous design yarn **9** here is represented by twisted pair **18** of yarns. It is obvious that more than two yarns can be used as well. This twisted arrangement forms spiral groove **17** along axial direction. Outer surfaces of twisted arrangement **18** provide support to winded thread **8**. External surface of winded layout of yarn **8** is sealed by compound **12** impermeable to vapors **4**.

[0035] Liquid **2** occupies volume between spiral **8** and groove **17**. Because surface of groove **17** repels liquid **2** it remains dry and free of liquid **2**. Supply of heat to some locations along length of thread **10** causes evaporation of liquid **2** in direct proximity of groove **17**. Vapors **4** are freely transported along groove **17** and condense on interface with liquid **2** at cooler locations along the length of thread **10**.

[0036] FIG. **4** shows thread **10** not in scale. Sealant **12**, liquid **2**, vapors **4**, and gases **5** are not shown. Yarn **8** is shown as single layer winding although other structures are equally allowable. Groove **17** and yarn **9** are shown as simple twist although their shape may have any other plaited form. Example of technologies suitable for production of such yarn structure was disclosed in co-pending patent applications Ser. No. 11/307,051. Other traditional technologies of yarn and braids production can be adapted in obvious manner to suite the same.

[0037] Although it is possible to produce yarns **11** and threads **10** as indefinitely long single volume **3**, from practical consideration such product will have extremely low reliability. Both yarns **11** and threads **10** of this invention contain intermediate seals **19** distributed along their length. FIG. **5** depictures this detail. Seals **19** segment volume **3** on collection of shorter independently sealed volumes. This results in creation of domains **6**.

[0038] FIG. **5** shows thread **10**/yarn **11** not in scale. Sealant **12**, yarns **8** and **9**, liquid **2**, vapors **4**, and gases **5** are not shown. There are variety well know techniques that allow for creation of seals **19**. As one example of such technique seal **19** can be formed by pressing a heater element against final yarn **11** or thread **10**. Because their composition contains thermoplastic materials those materials will melt creating impermeable seal **19**.

[0039] Because yarns **11** and threads **10** are closely packed inside structure of resulting textile material they have direct thermal contact with adjacent domains **6**. The shape of interface/boundary of adjacent domains can be very sophisticated 2D or 3D curve depending of particular type of textile material. This ensures sufficient heat transfer between domains **6**. It is also possible to further reduce size of domains by creating new seals **19**. This can be achieved by pressing or rolling heater element against existing textile. This will result in melting of thermoplastic components that will form desired pattern of new seals **19**.

[0040] Material **1** can be created using alternative design depictured on FIG. **6**. Textile structure utilizes yarns **8** for one side and yarns **9** for another. Resulting textile structure is sealed with surface coating **12** on both sides creating volume **3** in between yarns. Liquid **2** is disposed in volume occupied by yarns **8**, while portion of volume **3** allocated by yarns **9** remains dry due to repellent properties of their surface. Coating **12** prevents escape of vapors **4**.

[0041] Textile material **1** with this structure reveals interesting properties. Its normal thermal conductivity differs in opposite direction. When heat is supplied from side composed mostly of yarns **8** material **1** behaves as good thermal conductor transferring heat to side composed mostly of yarns **9**. When heat is applied in opposite direction to side mostly composed of yarns **9** material **1** reveals much lower thermal conductivity.

[0042] FIG. **6** shows textile **1** not in scale. Sealant **12**, liquid **2**, vapors **4**, and gases **5** are not shown. There are variety of standard know techniques that allow for creation of two sided textiles and application of volume and surface chemicals and sealants. Example of technology suitable for deposition of liquid **2** into volume **3** of material **1** is described in great details in co-pending patent application Ser. No. 11/307359.

[0043] There is yet another approach to production of material **1** illustrated on FIG. **6**. This approach uses yarn treatment. Segments of yarns exposed to one side of textile sheet are modified by means of additives (if necessary) to acquire repellent properties with respect to liquid **2**. Yarns segments exposed to opposite side of textile sheet are modified by means of additives (if necessary) to acquire high affinity properties with respect to liquid **2**. Resulting material is sealed and processed as it was described above.

[0044] Choice of additives depends on choice of liquid **2**, yarn material, and textile structure. List of suitable additives is well known to anyone experienced in art of yarn and fabric manufacturing. Affinity of these additives to selected liquids **2** can be found through online NIST database or other published sources.

[0045] FIG. **7** depictures yet alternative structure of textile **1**. It is formed by structuring yarns **8** and **9** in essentially parallel rows that may be a part of more complex form. FIG. **7** illustrates zigzag pattern while it is obvious that plurality of alternative patterns can be used. Rows **8** and **9** in this design can be obtained by deposition of chemical treatment(s) over existing textile. If textile has high affinity to liquid **2** then selected treatment chemicals should created stripe that will repel liquid **2**. If textile repels liquid **2** then selected treatment chemicals should created stripe that has high affinity to liquid **2**. Sealant **12** may be deposited either to seal full surface of textile **1** or to seal each of the rows individually.

[0046] FIG. **7** shows textile **1** not in scale. Sealant **12**, liquid **2**, vapors **4**, and gases **5** are not shown. There are variety standard know techniques that allow for creation of stripes in textiles and application of volume and surface chemicals and sealants. Example of technology suitable for deposition of liquid **2** into volume **3** of material **1** is described in great details in co-pending patent application Ser. No. 11/307359.

[0047] Area of application for invented textile materials comprises broad spectrum of technical and apparel applications. It also can be useful in designs of heat protective close and wearable electronic devices.

What is claimed is:

1. A textile comprising one or more sealed volumes and phase changing liquid composition disposed within said volumes, and inner surface of said volumes contains at least two distinct types of surface regions, wherein the first of said types has high affinity and the second of said types has low affinity to said liquid.

2. A textile of claim 1 wherein all said volumes are completely enclosed inside fibers, yarns, threads or other extended linear materials that compose said textile structure.

3. A textile of claim 1 composed of at least two types of extended linear materials, wherein the first of said types has high affinity and the second of said types has low affinity to said liquid and both are arranged in direct proximity of each other.

4. A textile of claim 3 wherein more than halve of said first type of linear material is arranged on one side of said textile.

5. A textile of claim 3 wherein said first type of linear material forms elementary patterns of rows.

6. A textile of claim 2 wherein some of said extended linear materials contains first porous member that repels said liquid, and said member separates parts of second member, wherein said second member exhibits high affinity to said liquid, and both members are enclosed by said volumes.

7. A textile of claim 6 wherein said second member has a helical structure.

8. A textile of claim 2 wherein some of said extended linear materials comprise at least two extended cavities connected by extended openings, wherein said openings have width that is less than smallest dimension of any of said cavities, and surface of at least one of said cavities has high affinity to said liquid, and there is at least one other cavity with surface that repels said liquid, wherein length of said cavities differs from length of said opening by less than fifty percent, and all said cavities disposed within said volumes.

9. A textile of claim 8 wherein said cavities form a helical structure.

10. A textile material of claim 2 wherein some of said extended linear materials comprise at least two extended tubular members with porous walls, and said members has extended common interface permeable to vapors of said liquid, and all said tubular members are disposed within said volumes, and at least one of said tubular members has inner surface that repels said liquid, and at least one of said members has inner surface with high affinity to said liquid.

11. A textile material of claim 10 wherein said porous walls are formed by fibers.

12. A textile material of claim 2 wherein some of said extended linear materials comprise at least two members twisted together and at least one member that is winded around said twisted members, wherein all said members are disposed within said volumes, and twisted members surface repels said liquid, and winded member surface has high affinity to said liquid.

13. An extended linear material of claim 6 comprising at least one member made of thermoplastic material.

14. An extended linear material of claim 7 comprising at least one member made of thermoplastic material.

15. An extended linear material of claim 8 comprising at least one member made of thermoplastic material.

16. An extended linear material of claim 9 comprising at least one member made of thermoplastic material.

17. An extended linear material of claim 10 comprising at least one member made of thermoplastic material.

18. An extended linear material of claim 11 comprising at least one member made of thermoplastic material.

19. An extended linear material of claim 12 comprising at least one member made of thermoplastic material.

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