

1 COOLEY LLP
REUBEN H. CHEN (228725)
2 rchen@cooley.com
KYLE D. CHEN (239501)
3 kyle.chen@cooley.com
3175 Hanover Street
4 Palo Alto, CA 94304-1130
Telephone: (650) 843-5000
5 Facsimile: (650) 849-7400

6 Attorneys for Defendant and
Counter-Claim Plaintiff
7 COOLER MASTER CO., LTD.
and Defendant CMI USA, INC.
8

9 UNITED STATES DISTRICT COURT
10 NORTHERN DISTRICT OF CALIFORNIA
11

12 AAVID THERMALLOY LLC,
13 Plaintiff,
14 v.
15 COOLER MASTER CO., LTD. and
16 CMI USA, INC.,
17 Defendants.

18 COOLER MASTER CO., LTD,
19 Counter-Claim Plaintiff,
20 v.
21 AAVID THERMALLOY LLC and
22 BOYD CORPORATION
23 Counter-Claim Defendants.
24
25
26
27
28

Case No. 4:17-cv-05363-JSW

**SUPPLEMENTAL DECLARATION
OF DR. HIMANSHU POKHARNA IN
RESPONSE TO DECLARATION OF
MR. NELSON GERNERT**

1 I, Himanshu Pokharna, Ph.D., declare:

2 1. I previously provided a declaration in connection with claim construction in this
3 matter (originally served on June 29, 2018; corrected and re-served on July 9, 2018) (“Pokharna
4 Declaration”), in which I “reserve[d] the right to supplement th[at] declaration to rebut any opinion,
5 statement, evidence, or position taken by Aavid in its claim construction positions.” (See Pokharna
6 Declaration, ¶¶ 5.) On behalf of Aavid, Mr. Nelson Gernert provided a responsive declaration
7 (served on July 13, 2018) (“Gernert Declaration”). I now provide this supplemental declaration in
8 response to the Gernert Declaration.

9 2. I have been informed that Defendants, to narrow their disputes with Aavid, have
10 modified their proposed construction of “vapor chamber” in light of the Gernert Declaration to
11 become: “Enclosed and **hermetically** sealed void or cavity in which a **suitable quantity of liquid**
12 **working fluid** is present to be evaporated (or vaporized) and condensed to transport or spread
13 heat.” My prior opinions concerning “vapor chamber” in the Pokharna Declaration fully support the
14 modified construction by Defendants. For example, in paragraph 31 of the Pokharna Declaration, I
15 pointed out that “the vapor chamber is in ‘[a] state of being sealed off from external or
16 environmental influences’ or in ‘isolation,’” which supports the modified construction that the “void
17 or cavity” is “enclosed and hermetically sealed.” (See also Pokharna Declaration, ¶¶ 28, 30.) My
18 opinions support the use of the word “hermetic,” which is defined as “a: AIRTIGHT <~ seal> b:
19 impervious to external influence” by Merriam Webster’s Collegiate Dictionary 10th Edition
20 (Copyright 1998) and “a. of alchemy: sealed” by Webster’s New Dictionary (Copyright 1997). (See
21 Exhibit C.) As to the change from “suitable quantity of liquid” to “working fluid,” in my opinion, a
22 person of ordinary skill in the art would have considered the two phrases to be interchangeable in the
23 context of Defendants’ proposed constructions before and after the modification, the patents-in-suit,
24 and the heat pipe related art at the time of the alleged invention. In my opinion, in Defendants’
25 modified construction, the phrase “a working fluid ... to transport or spread heat” makes clear that
26 the “fluid” is “working ... to transport or spread heat,” which is no different from “a suitable
27 quantity of liquid ... to transport or spread heat.” The reason is that the “suitab[ility]” of the fluid’s
28 “quantity” is implied because the fluid is “working ... to transport or spread heat.” The book “Heat

Pipes,” cited by Mr. Gernert, also states that a “working fluid” is a basic component of a heat pipe. (See, e.g., Gernert Declarations, ¶¶ 6, 8.) Thus, there should be no dispute that a “working fluid” is a proper phrase to use in the construction.

3. Mr. Gernert also seems to assert that there were two separate types of devices at the time of the alleged invention: “thermosiphons” and “heat pipes” as if there was strictly no overlap between them. The strict distinction proposed by Mr. Gernert appears to be based on whether only “gravity” or “capillary forces” were involved in the working fluid’s movements inside the devices. But as shown in the heat pipe related literatures attached hereto (Exhibit D), thermosiphons (or sometimes spelled as “thermosyphons”) were often considered to be a type of heat pipes in the field around or before the time of the alleged invention. (See, e.g., U.S. Patent No. 6,269,865 (issued in 2001) at 1:54-55 (“This kind of heat pipe is call [sic] as a ‘**thermosyphon-loop heat pipe**’”) (emphasis added); see also [https://doi.org/10.1016/S1359-4311\(96\)00058-0](https://doi.org/10.1016/S1359-4311(96)00058-0) (*Applied Thermal Engineering*, Vol. 17, Issue 6, June 1997, pp. 561-568 (“a **thermosyphon heat pipe** heat exchanger is under investigation”) (emphasis added)); <http://adsabs.harvard.edu/abs/1992JSMET..58.2543K> (“Title: Heat transfer characteristics of two-phase **thermosyphon heat pipe** ... Publication Date: 08/1992 [A] a two-phase **thermosyphon heat pipe** is developed in comparison with experimental data.”) (emphasis added); U.S. Patent No. 4,421,100, issued in 1983 and entitled “**Thermosiphon Heat Pipe** Hot Water Appliance” (emphasis added).) And there was no requirement that thermosiphons could rely on *only* gravity for the working fluid’s movements, or that heat pipes could rely on *only* capillary forces. For example, U.S. Patent No. 6,269,865, issued on August 7, 2001, described a “single-loop **thermosyphon heat pipe** [that] is designed as a multiple-loop **capillary heat pipe** which is connected in a series to a bundle of parallel **capillary pipes**.” (*Id.* at 1:62-65 (emphasis added).) Indeed, there were thermosiphons that also had capillary structures and thus used capillary forces to help move the working fluid, making the strict distinction between thermosiphons and heat pipes based on the use of gravity or capillary forces as proposed by Mr. Gernert meaningless. (See *id.*) Further, gravity is in many cases present, and therefore is likely involved in the movement of the working fluid in heat pipes, and thus may help move the working fluid in the desired direction, too. (See, e.g., *id.* at 5:36-37 (“[T]he gravitational effect of the vertical

1 liquid segments will enhance the heat pipe performance.”.) Thus, the assertion that gravity is
2 excluded from the movement of the working fluid in heat pipes is nonsensical. This also makes the
3 purported strict distinction between thermosiphons and heat pipes based on the use of gravity or
4 capillary forces as proposed by Mr. Gernert meaningless.

5 4. I also disagree with Mr. Gernert’s suggestion that “grooves” formed in the walls of a
6 heat pipe are somehow not “wicks” (*see* Gernert Declaration, ¶¶ 7, 26). (*Cf.* U.S. Patent No.
7 6,938,680 filed in 2003 and entitled “Tower Heat Sink with Sintered **Grooved Wick**”) (emphasis
8 added.) I further disagree with Mr. Gernert’s assertion that wicks must be “a *separate structure*
9 applied to the interior walls of the heat pipe, such as sintered powder or wire mesh wick” (Gernert
10 Declaration, ¶ 7 (italics in original)). (*Cf. An Introduction to Heat Pipes – Modeling, Testing, and*
11 *Applications* by G.P. Peterson (Copyright 1994) at 5, Fig. 1.4 (referring to an “Axial Groove”
12 structure formed as part of a heat pipe’s wall as one of the “Typical heat pipe **wicking** configurations
13 and structures.” (emphasis added).) Thus, in my opinion, “grooves” are a type of “wicks,” which do
14 not have to be a “separate structure” of a “separate material” that are “added” to a heat pipe, as
15 asserted by Mr. Gernert (Gernert Declaration, ¶¶ 7, 26). I also note that the specification of the
16 patents-in-suit does not recite any “grooves” to create capillary forces.

17
18 *****

19 Pursuant to 28 U.S.C. § 1746, I declare under the penalty of perjury that the foregoing is true
20 and correct to the best of my knowledge. Executed on July 27, 2018 in Palo Alto, CA 94304.

21
22
23
24
25 

26 Himanshu Pokharna
27
28

Exhibit C

The Voice of Authority™

Merriam Webster's Collegiate Dictionary

TENTH EDITION

America's best-selling dictionary



Merriam-Webster:
Carrying forward Noah Webster's
legacy since 1847



Merriam- Webster's Collegiate® Dictionary

TENTH EDITION

Merriam-Webster, Incorporated
Springfield, Massachusetts, U.S.A.



A GENUINE MERRIAM-WEBSTER

The name *Webster* alone is no guarantee of excellence. It is used by a number of publishers and may serve mainly to mislead an unwary buyer.

*Merriam-Webster*TM is the name you should look for when you consider the purchase of dictionaries or other fine reference books. It carries the reputation of a company that has been publishing since 1831 and is your assurance of quality and authority.

Copyright © 1998 by Merriam-Webster, Incorporated

Philippines Copyright 1998 by Merriam-Webster, Incorporated

Library of Congress Cataloging in Publication Data
Main entry under title:

Merriam-Webster's collegiate dictionary. — 10th ed.

p. cm.

Includes index.

ISBN 0-87779-708-0 (unindexed : alk. paper). — ISBN 0-87779-709-9 (indexed : alk. paper). — ISBN 0-87779-710-2 (deluxe indexed : alk. paper). — ISBN 0-87779-707-2 (laminated cover, unindexed).

1. English language—Dictionaries. I. Merriam-Webster, Inc.

PE1628.M36 1998

423—dc21

97-41846
CIP

Merriam-Webster's Collegiate® Dictionary, Tenth Edition principal copyright 1993

COLLEGIATE is a registered trademark of Merriam-Webster, Incorporated

All rights reserved. No part of this book covered by the copyrights hereon may be reproduced or copied in any form or by any means—graphic, electronic, or mechanical, including photocopying, taping, or information storage and retrieval systems—without written permission of the publisher.

Made in the United States of America

2021222324RMcN98

3 slang : MARIJUANA 2 — herb-like
 y-bev adj
 adj (1646) 1 a : of, relating to, or
 herb b of a stem : having little or no
 for a single growing season 2 : hav-
 ing a leaf

herbaceous vegetation (as grass) esp.
 succulent parts of herbaceous plants
 : a book about plants esp. with refer-
 s 2 archaic : HERBARIUM 1
 o, or made of herbs
 89) 1 : one who practices healing by
 herbs or grows herbs
 -her-v, n, pl -ta \-e-a\ (1776) 1 : a
 tens usu. mounted and systematically
 or that houses an herbarium
 T 1

asoned with herbs
 herba + ISV -cide\ (1899) : an agent
 growth — her-bi-cid-al \-(h)er-ba-'si-
 -e-a\ adv
 \ n [NL *Herbivora*, group of mammals,
 : a plant-eating animal
 'bi-vo-a\ adj [NL *herbivorus*, fr. L *herba*
 : feeding on plants — her-bi-vo-o-ry

1 [ML *herba Roberti*, prob. fr. *Robertus*
 lic] (13c) : a sticky low geranium (Ge-
 reddish purple flowers
 -er-kyū-lē-a\ adj (1593) 1 : of, relating
 s 2 often not cap : of extraordinary
 ulty
 r. Gk *Hēraklēs* 1 : a mythical Greek
 ngth and esp. for performing 12 labors
 (gen. *Herculis*) : a northern constella-
 d Lyra
 -klob\ n (1847) 1 : a small prickly
 of the ginseng family — called also
 kly southern U.S. tree (*Zanthoxylum*

d; akin to OHG *hera* herd, MW *corda*
 bef. 12c) 1 a : a number of animals
 human control b : a congregation of
 (1) : a group of people usu. having a
 emblage of like things b : the undis-
 the individual prophets from the ~
 e \-jik\ adj
 lead, or drive as if in a herd (seventy-
 six or eight teachers — W. A. White)
 2 : to place in a group ~ vi
 d 2 : to place oneself in a group : AS-

that herds; specif : HERDSMAN 1
 1 : a manager, breeder, or tender of

akin to OHG *hier* here, OE *hē* he (bef.
 turn ~) — often used interjectionally
 NOW (~ it's morning already) c : in
 a paper there 2 : at or in this point,
 3 : in the present life or state 4
 interjectionally in rebuke or encourage-
 tionally to express resolution or
 of a difficult or unpleasant undertak-
 : having no interest or relevance : of
 er here nor there to a real sailor)
 iphesis esp. after a demonstrative pro-
 a demonstrative adjective (this book
 phasis after a demonstrative adjective
 is ~ book)

ere-about \-baüt\ adv (13c) : in this

12c) 1 : after this in sequence or in
 state

1 : FUTURE 2 : an existence beyond

UTURE
 resent time — used with the (man's
 — W. H. Whyte)

one place and another 2 : from time

aways \-wáz\ adv (14c) dial : HERE-

by this means

ent\ n [ML *hereditamentum*, fr. LL
heres] (15c) : heritable property

son\ n (1831) : an advocate of the
 s in human beings can be accounted
 ties — hereditarian adj

adj [L *hereditarius*, fr. *hereditas*] (15c)
 transmittable from parent to offspring
 y one's predecessors 2 a : received
 ired to pass by inheritance or by re-
 possession through inheritance or by
 ablished by tradition (~ enemies) 4

heredity *syn* see INNATE — her-red-i-

heredité, fr. L *hereditat*, *hereditas*, fr.
 R] (ca. 1540) 1 a : INHERITANCE b
 the qualities and potentialities geneti-
 s b : the transmission of such quali-
 through the genes

Her-e-ford \hər-fərd sometimes 'her-a-\ n [*Hereford* former county in
 England] (1805) : any of a breed of hardy red-coated beef cattle of
 English origin with white faces and markings

here-in \hīr-'in\ adv (bef. 12c) : in this

here-in-above \hīr-'in-a-'bov\ adv (ca. 1812) : at a prior point in this
 writing or document

here-in-after \hīr-'a-'naf-tər\ adv (1590) : in the following part of this
 writing or document

here-in-be-fore \hīr-'in-bi-'fər\ adv (1687) : in the preceding
 part of this writing or document

here-in-be-low \bi-'lō\ adv (1946) : at a subsequent point in this writ-
 ing or document

here-of \hīr-'əv, -'āv\ adv (bef. 12c) : of this

here-on \-'on, -'ən\ adv (12c) : on this

Here-ro \hə-'rer-(j)ō, 'her-a-'rō\ n, pl *Herero* or *Hereros* (1880) : a
 member of a Bantu people of central Namibia

he-re-si-arch \hə-'re-zē-'ārk, 'her-a-'sē-\ n [LL *haeresiarcha*, fr. LGk
haesiarchēs, fr. *haeresis* + Gk -archēs -arch] (1624) : an originator or
 chief advocate of a heresy also *he-re-si-ec* \hīr-'ə-tik\ adj (15c) 1 : of,

her-e-sy \hīr-'ə-sē\ n, pl -sies [ME *heresie*, fr. OF, fr. LL *haeresis*, fr.
 LGk *haeresis*, fr. Gk, action of taking, choice, sect, fr. *hairein* to take]
 (13c) 1 a : adherence to a religious opinion contrary to church
 dogma b : denial of a revealed truth by a baptized member of the
 Roman Catholic Church c : an opinion or doctrine contrary to
 church dogma 2 a : dissent or deviation from a dominant theory,
 opinion, or practice b : an opinion, doctrine, or practice contrary to
 the truth or to generally accepted beliefs or standards

her-e-tic \hīr-'ə-tik\ n (14c) 1 : a dissenter from established church
 dogma; esp : a baptized member of the Roman Catholic Church who
 disavows a revealed truth 2 : one who dissents from an accepted
 belief or doctrine : NONCONFORMIST

her-e-ti-cal \hīr-'ə-tik\ adj (12c) 1 : of, relating to, or character-
 ized by heresy 2 : of, relating to, or character-
 ized by departure from accepted beliefs or standards : UNORTHODOX

her-e-ti-cal-ly \hīr-'ə-tik-ə-lē\ adv

here-to \hīr-'tū\ adv (12c) : to this writing or document

here-to-fore \hīr-'tō-fər, -'fər, hīr-'tā-\ adv (13c) : up to this time
 : HITHERTO

here-un-der \hīr-'ən-dər\ adv (15c) : under or in accordance with this
 writing or document

here-un-to \hīr-'ən-(j)ō, hīr-'ən-'tū\ adv (1509) : to this

here-up-on \hīr-'ə-pōn, -'pān, hīr-'ə-\ adv (12c) : on this : immedi-
 ately after this

here-with \hīr-'wīth, -'wīth\ adv (bef. 12c) 1 : with this communica-
 tion : enclosed in this 2 : HEREBY

He-rez \hə-'rez\ or He-riz \-'rīz\ n [*Herez*, *Heriz*, town in Iran] (ca.
 1922) : a Persian rug characterized by a large central geometric medallion
 and by angular floral designs

her-i-ot \hīr-'ə-ōt\ n [ME, fr. OE *heregæte*, pl., military equipment,
 fr. *here* army (akin to OHG *heri* army) + *gæte* equipment — more at
 HARRY] (bef. 12c) : a feudal duty or tribute due under English law to a
 lord on the death of a tenant

her-i-ta-bil-i-ty \hīr-'ə-tā-'bi-lē-tē\ n (1832) 1 : the quality or state of
 being heritable 2 : the proportion of observed variation in a particu-
 lar trait (as intelligence) that can be attributed to inherited genetic
 factors in contrast to environmental ones

her-i-ta-ble \hīr-'ə-tā-'bəl\ adj (14c) 1 : capable of being inherited or
 of passing by inheritance 2 : HEREDITARY

her-i-tage \hīr-'ə-tij\ n [ME, fr. MF, fr. *hériter* to inherit, fr. LL *heredita-*
re, fr. L *hered-*, *heres* here — more at HEIR] (13c) 1 : property that
 descends to an heir 2 a : something transmitted by or acquired from a
 predecessor : LEGACY, INHERITANCE b : TRADITION 3 : something
 possessed as a result of one's natural situation or birth : BIRTHRIGHT
 (the nation's ~ of tolerance)

her-i-tor \hīr-'ə-tər\ n (15c) : one that inherits : INHERITOR

herky-jerky \hīr-'kē-'jər-'kē\ adj [redupl. of *jerky*] (1957) : character-
 ized by sudden, irregular, or unpredictable movement or style

herm \hərm\ n [L *hermes*, fr. Gk *hermēs* statue of Hermes, herm, fr.
Hermēs] (ca. 1580) : a statue in the form of a square stone pillar sur-
 mounted by a bust or head esp. of Hermes

herma \hīr-'mə\ n, pl *her-mae* \-'mē, -'mī\ or *her-mai* \-'mī\ (1638)
 : HERM

her-maph-ro-dite \hīr-'ma-frā-'dit\ n [ME *hermafrodite*, fr. L *her-*
maphroditus, fr. Gk *hermaphroditos*, fr. *Hermaphroditos*] (14c) 1 : an
 animal or plant having both male and female reproductive organs 2
 : something that is a combination of diverse elements — *hermaphro-*
dite adj — *her-maph-ro-dit-ic* \hīr-'ma-frā-'di-tik\ adj — *her-*
maph-ro-dit-ism \-'ma-frā-'di-ti-zəm\ n

Her-maph-ro-di-tus \hīr-'ma-frā-'di-təs\ n [L, fr. Gk *Hermaph-*
roditos, fr. *Hermēs* + *Aphroditē* Aphrodite] : a son of Hermes and
 Aphrodite who becomes joined in one body with a nymph while bath-
 ing

her-ma-ty-p-ic \hīr-'mə-'ti-pik\ adj [Gk *herma* prop, reef + *typtēin* to
 strike, coin + *-ic* — more at TYPE] (1950) : building reefs (~ corals)

her-me-neu-ti-cal \hīr-'mə-'ni-ti-kəl, -'nyū-, or *her-me-neu-tik* \-'tik\
 adj [Gk *hermeneutikos*, fr. *hermeneuein* to interpret, fr. *hermēneus*
 interpreter] (1678) : of or relating to hermeneutics : INTERPRETATIVE

— *her-me-neu-ti-cal-ly* \-'ti-k(ə)-lē\ adv

her-me-neu-tics \-'tik-s\ n pl but sing or pl in constr (1737) : the study of
 the methodological principles of interpretation (as of the Bible)

Her-mes \hīr-'(m)ēz\ n [L, fr. Gk *Hermēs*] : a Greek god of com-
 merce, eloquence, invention, travel, and theft who serves as herald and
 messenger of the other gods — compare MERCURY

Hermes Tris-me-gis-tus \-'tris-mē-'jis-təs\ n [ML, fr. Gk *Hermēs*
trismegistos, lit., Hermes (thrice greatest)] : a legendary author of works
 embodying magical, astrological, and alchemical doctrines

her-met-ic \hīr-'me-tik\ also *her-met-i-cal* \-'ti-kəl\ adj [NL *her-*
meticus, fr. *hermet*, *Hermes Trismegistus*] (1603) 1 often cap a : of
 or relating to the Gnostic writings or teachings arising in the first three
 centuries A.D. and attributed to Hermes Trismegistus b : relating to or
 characterized by occultism or abstruseness : RECONDITE 2 [fr. the
 belief that Hermes Trismegistus invented a magic seal to keep vessels
 airtight] a : AIRTIGHT (~ seal) b : impervious to external influence

(trapped inside the ~ military machine — Jack Newfield) c : RE-
 CLUSE, SOLITARY (leads a ~ life) — *her-met-i-cal-ly* \-'ti-k(ə)-lē\ adv

her-met-i-cism \-'me-tā-'si-zəm\ n, often cap (1897) : HERMETISM

her-met-ism \hīr-'mə-'ti-zəm\ n, often cap (1897) 1 a : a system of
 ideas based on hermetic teachings b : adherence to or practice of
 hermetic doctrine 2 : the practice of being hermetically mysterious (it
 is not ~, willful ~, if the message of their art is veiled and indirect —
 R. I. Goldwater) — *her-met-ist* \-'ma-tist\ n

her-mit \hīr-'mət\ n [ME *eremite*, fr. OF, fr. LL *eremita*, fr. LGk *erē-*
mītēs, fr. Gk, adj., living in the desert, fr. *erēma* desert, fr. *erēmos* deso-

late] (12c) 1 a : one that retires from society and lives in solitude
 esp. for religious reasons : RECLUSE b obs : BEADSMAN 2 : a spiced
 molasses cookie — *her-mit-ism* \hīr-'mə-'ti-zəm\ n

her-mit-age \hīr-'mə-tij\ n (14c) 1 a : the habitation of a hermit b
 : a secluded residence or private retreat : HIDEAWAY c : MONASTERY 2
 : the life or condition of a hermit

Her-mit-age \hīr-'mi-'tāzh\ n [Tain-l'Ermitage, commune in France]
 (1680) : a red or white Rhone valley wine

her-mit crab n (1735) : any of nu-
 merous chiefly marine decapod crusta-
 ceans (esp. families Diogenidae,
 Paguridae, and Parapaguridae) hav-
 ing soft asymmetrical abdomens and
 occupying the empty shells of gas-
 tropods

Her-mi-tian matrix \-'mē-shən-,
 hīr-'mi-shən-\ n [Charles Hermite
 †1901 Fr. mathematician] (1935) : a
 square matrix having the property
 that each pair of elements in the *i*th
 row and *j*th column and in the *j*th
 row and *i*th column are conjugate complex numbers

hern \hərn, 'hərn\ dial var of HERON

her-nia \hīr-'nē-\ n, pl -ni-as or -ni-ae \-'nē-ē, -'nē-\ [L — more at
 YARN] (14c) : a protrusion of an organ or part through connective
 tissue or through a wall of the cavity in which it is normally enclosed
 — called also *rupture* — *her-ni-al* \-'nē-\ adj

her-ni-ate \hīr-'nē-'āt\ vi -at-ed; -at-ing (ca. 1922) : to protrude
 through an abnormal body opening : RUPTURE — *her-ni-a-tion* \hīr-
 'nē-'ā-shən\ n

he-ro \hīr-'(j)ō, 'hē-(j)ō\ n, pl *heroes* [L *heros*, fr. Gk *hērōs*] (14c) 1
 a : a mythological or legendary figure often of divine descent endowed
 with great strength or ability b : an illustrious warrior c : a man
 admired for his achievements and noble qualities d : one that shows
 great courage 2 a : the principal male character in a literary or dra-
 matic work b : the central figure in an event, period, or movement 3
 pl usu *heros* : SUBMARINE 4 : an object of extreme admiration and
 devotion : IDOL

Hero n [L, fr. Gk *Hērō*] : a legendary priestess of Aphrodite loved by
 Leander

he-ro-ic \hī-'rō-ik\ also *her-'ō* or *hē-'rō* also *he-ro-i-cal* \-'i-kəl\ adj
 (1549) 1 : of, relating to, or resembling heroes esp. of antiquity 2 a
 : exhibiting or marked by courage and daring b : supremely noble or
 self-sacrificing 3 a : of impressive size, power, extent, or effect : PO-
 TENT (~ dossier) b (1) : of great intensity : EXTREME

DRASTIC (~ effort) (2) : of a kind that is likely only to be undertaken
 to save a life (~ surgery) 4 : of, relating to, or constituting drama
 written during the Restoration in heroic couplets and concerned with a
 conflict between love and honor — *he-ro-i-cal-ly* \-'i-k(ə)-lē\ adv

heroic n (1596) 1 : a heroic verse or poem 2 pl a : flamboyantly
 heroic language or action b : heroic action or behavior c : deter-
 mined effort esp. in the face of difficulty

heroic couplet n (1889) : a rhyming couplet in iambic pentameter

he-ro-i-com-ic \hī-'rō-'i-'k(ə)-mīk\ or *he-ro-i-com-i-cal* \-'k(ə)-mī-kəl\ adj
 [F *heroïque*, fr. *héroïque* heroic + *comique* comic] (1756) : comic
 by being ludicrously noble, bold, or elevated

heroic poem n (1693) : an epic or a poem in epic style

heroic stanza n (ca. 1922) : a rhymed quatrain in heroic verse with a
 rhyme scheme of *abab* — called also *heroic quatrain*

heroic verse n (1586) 1 : dactylic hexameter esp. of epic verse of
 classical times — called also *heroic meter* 2 : the iambic pentameter
 used esp. in English epic poetry during the 17th and 18th centuries —
 called also *heroic line*, *heroic meter*

her-o-in \hīr-'ə-wən\ n [fr. *heroin*, a trademark] (1898) : a strongly
 physiologically addictive narcotic $C_{21}H_{23}NO_5$ that is made by acetyla-
 tion of but is more potent than morphine and that is prohibited for
 medical use in the U.S. but is used illicitly for its euphoric effects —
he-ro-in-ism \-'wə-'ni-zəm\ n

her-o-ine \hīr-'ə-wən, 'hīr-\ n [L *heroina*, fr. Gk *hērōinē* fem. of *hērōs*]
 (1609) 1 a : a mythological or legendary woman having the qualities
 of a hero b : a woman admired and emulated for her achievements
 and qualities 2 a : the principal female character in a literary or
 dramatic work b : the central female figure in an event or period

her-o-ism \hīr-'ə-wi-zəm\ also *hīr-* (1717) 1 : heroic conduct esp.
 as exhibited in fulfilling a high purpose or attaining a noble end 2
 : the qualities of a hero

he-ro-ize \hīr-'(j)ō-'iz, 'hīr-(j)ō-; 'her-'ə-wi-z\ vt -ized; -iz-ing (1738)
 : to make heroic

her-on \hīr-'ən\ n, pl *herons* also *heron* [ME *heiroun*, fr. MF *hairon*,
 of Gmc origin; akin to OHG *heigaro* heron] (14c) : any of various
 long-necked wading birds (family Ardeidae) with a long tapering bill,
 large wings, and soft plumage

her-on-ry \-'ən-rē\ n, pl -ries (1616) : a heron rookery

hero-worship vt (1884) : to feel or express hero worship for — *hero-*
worshiper n

hero worship n (1774) 1 : veneration of a hero 2 : foolish or exces-
 sive adulation for an individual

\\ abut \\ kitten, F table \\ further \\ ash \\ ace \\ mop, mar
 \\ out \\ chin \\ bet \\ easy \\ go \\ hit \\ ice \\ job
 \\ sing \\ go \\ law \\ boy \\ thin \\ thin \\ the \\ foot
 \\ yet \\ vision \\ k, \\ , oe, \\ , ue, \\ see Guide to Pronunciation



hermit crab

\$7.95 US/\$9.95 CAN

WEBSTER'S

NEW

DICTIONARY

- Over 65,000 Definitions
- 336 Pages
- Current Scientific and Computer Terms Throughout
- Clear, Up-to-Date Definitions
- Easy-to-Read Typeface
- Over 8,000,000 Copies Sold

ALL BASIC WORDS
FOR SCHOOL, HOME,
AND OFFICE

NEW, UP-TO-DATE EDITION
OF WORLDWIDE
BESTSELLER

Cooley LLP
Library

MAY 01 2012

4401 Eastgate Mall
San Diego, CA 92121

Webster's New Dictionary

Promotional Sales Books, Inc.
New York, NY

Copyright © 1997 by
Promotional Sales Books, Inc.

All rights reserved. No part of this book may be reproduced or transmitted in any form.

Printed in the United States of America

ISBN: 1-57723-360-3

2002 Edition

An American BookWorks Corporation Production

This book is not published by the original publishers of
WEBSTER'S DICTIONARY or by their successors.

disease or condition relating to inflammation of the liver.
hep'tagon *n.* plane figure with seven sides, angles. **-heptag'onal** *a.* **-hep'tarchy** (-ki) *n.* rule by seven. **-hep'tateuch** (-tuk) *n.* first seven books of the Old Testament.
her *pron. obj., possess., of she. -herself*, emphatic, reflex, of *she, her*; in her proper character.
her'ald *n.* officer who makes royal proclamations, arranges ceremonies, keeps records of genealogies and those entitled to armorial bearings, etc.; messenger, envoy. **-v.t.** announce; proclaim the approach of. **-heral'dic** *a.* **-her'aldry** *n.* science of heraldic bearings.
herb *n.* plant with a soft stem which dies down after flowering; plant of which parts are used for medicine, food or scent. **herba'ceous** (-shus) *a.* of or like a herb. **herb'age** *n.* herbs; grass, pasture. **herb'al** *a.* of herbs. **-n.** book on herbs. **herb'alist** *n.* writer on herbs; dealer in medicinal herbs. **-herbar'ium** *n.* collection of dried plants. **-herb'y** *a.* of herbs.
Hercu'lean *a.* very strong; very difficult.
herd *n.* number of animals feeding or traveling together; large number of people (*in contempt*); herdsman. **-v.t.** go to a herd. **-v.t.** tend (a herd); crowd together. **herds'man** *n.*
here *adv.* in this place; at or to this point.
hered'ity *n.* tendency of an organism to transmit its nature to its descendants. **hered'itary** *a.* descending by inheritance; holding office by inheritance; that can be transmitted from one generation to another. **-hered'itarily** *adv.* **-heredit'ament** *n.* something that can be inherited. **-heritable** *a.* that can be inherited. **-her'itage** *n.* that which may be or is inherited; portion or lot.
her'esy *n.* opinion contrary to the orthodox opinion. **-here'siarch** originator or leader of a heresy. **-her'etic** *n.* holder of a heresy. **-heret'ical** *a.* heret'ically *adv.*
hermaph'rodite *n.* person or animal with the characteristics of both sexes.
hermet'ic *a.* of alchemy; sealed. **hermet'ic sea'ling**, airtight closing of a vessel by melting the edges together, etc.; **hermet'ically** *adv.*
her'mit *n.* person living in solitude, esp. from religious motives. **-her'mitage** *n.* his abode. **-her'mit-crab'** *n.* kind of crab living in discarded mollusk shells.
hern'ia *n.* protrusion of an internal organ through the wall of tissue that encloses it; rupture.
he'ro *n.* illustrious warrior; one greatly regarded for achievements or qualities
 chief man in a poem, play, or story;

demigod. **-hero'ic** *a.* **-hero'ically** *adv.*
her'oism *n.* **-he'ro-worshipper** *n.*
her'oin *n.* strongly addictive narcotic drug derived from morphine.
her'on *n.* long-legged, long-necked wading bird. **-her'onry** *n.* place where herons breed.
her'pes *n.* any of several skin diseases, including shingles (*herpes zoster*) and cold sores (*herpes simplex*).
herr'ing *n.* familiar sea-fish. **-herr'ing-bone** *n.* stitch or pattern of zigzag lines.
hertz *n.* (radio) unit of frequency.
hes'itate *v.i.* hold back, feel, show, indecision; be reluctant. **-hes'itant** *a.* **hes'itantly** *adv.* **-hes'itancy** *n.* indecision, doubt. **-hesita'tion** *n.*
hess'ian *n.* coarse jute cloth.
het'erodox *a.* not orthodox. **-het'ero-doxy** *n.*
heterody'ning *n.* (radio) superimposing of a wave on another of different length to produce a beat of audible frequency.
heteroge'neous *a.* composed of diverse elements. **-heterogene'ity** *n.*
hew *v.t. and i.* chop or cut with ax or sword. **-hew'er** *n.*
hex'agon *n.* figure with six sides, angles. **-hexag'onal** *a.* **-hexam'eter** *n.* verse line of six feet.
hey'day *n.* bloom, prime, height of one's vigor, success.
hia'tus *n.* gap in a series; break between two vowels, esp. in consecutive words.
Hiber'nian *a.* of, pert. to Ireland, Irish (person). **-hibernianism**, **Hiber'nicism** *n.* Irish idiom.
hibernate *v.i.* pass the winter, esp. in torpor. **-hiberna'tion** *n.*
hibis'cus *n.* tropical plant of the mallow family.
hiccup *n.* spasm of the breathing organs with an abrupt sound. **-v.i.** have this.
hick *n.* farmer; unsophisticated country person. **-a.**
hick'ory *n.* N. Amer. tree like walnut with tough wood and edible nuts.
hidal'go *n.* lesser Spanish nobleman.
hide *n.* skin, raw or dressed. **-hide'bound** *a.* with skin tight to body as cattle. (*sl.*) prejudiced, narrow-minded.
hide *n.* old measure of land.
hide *v.t.* put or keep out of sight; conceal, keep secret. **-v.i.** conceal oneself. **hid'den** *a.*
hid'eous *a.* repulsive, revolting. **hideously** *adv.*
hie *v.i. and refl.* go quickly; betake (oneself).
hierarch (-k) *n.* chief priest. **-hi'erarchy** *n.* graded priesthood or other organization. **-hierarch'ical** *a.* **-hierat'ic** *a.* of the priests

Exhibit D



US006269865B1

(12) **United States Patent**
Huang

(10) **Patent No.:** **US 6,269,865 B1**
(45) **Date of Patent:** **Aug. 7, 2001**

(54) **NETWORK-TYPE HEAT PIPE DEVICE**

(76) Inventor: **Bin-Juine Huang**, No. 7, Lane 52,
Wen-Chou Street, Taipei (TW)

(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/137,080**

(22) Filed: **Aug. 20, 1998**

(30) **Foreign Application Priority Data**

Aug. 22, 1997 (TW) 86112063

(51) **Int. Cl.**⁷ **F28D 15/00**

(52) **U.S. Cl.** **165/104.26; 165/104.33;**
165/80.4; 361/700; 174/15.2; 257/715

(58) **Field of Search** **165/104.21, 104.33,**
165/104.26, 80.4, 185; 361/689, 699, 698,
700; 174/15.1, 15.2; 257/714, 715, 716

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,550,774 * 11/1985 Andres et al. 165/104.21
4,612,978 9/1986 Cutchaw 165/104.33
4,766,885 * 8/1988 Muramatsu 165/104.21
5,203,399 4/1993 Koizumi 165/104.22
5,303,768 4/1994 Alario et al. 165/104.26
5,316,077 * 5/1994 Reichard 165/104.33
5,381,859 * 1/1995 Minakami et al. 165/80.3
5,394,936 3/1995 Budelman 165/104.33
5,441,102 * 8/1995 Burward-Hoy 165/104.33
5,646,824 * 7/1997 Ohashi et al. 361/699
5,697,428 12/1997 Akachi 165/104.21
5,713,413 2/1998 Osakabe et al. 165/104.33
5,725,049 3/1998 Swanson et al. 165/104.26
5,729,995 * 3/1998 Tajima 165/104.33
5,743,325 * 4/1998 Esposto 165/41
5,764,483 * 6/1998 Ohashi et al. 361/699
5,845,702 12/1998 Dinh 165/104.21
5,998,863 * 12/1999 Kobayashi et al. 257/714

6,005,772 * 12/1999 Terao et al. 257/714
6,016,251 * 1/2000 Koide et al. 165/80.4
6,115,252 * 9/2000 Ohta et al. 361/700
6,137,682 * 10/2000 Ishimine et al. 361/700
6,164,368 * 12/2000 Furukawa et al. 165/104.33
6,166,907 * 12/2000 Chien 361/699

* cited by examiner

Primary Examiner—Marvin M. Lateef

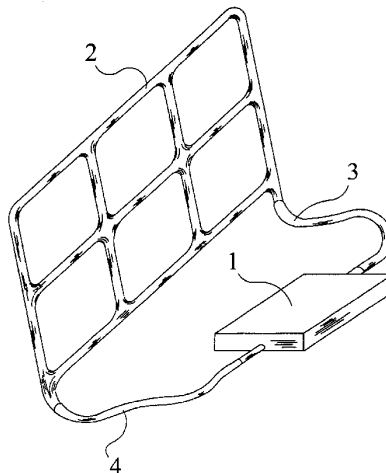
Assistant Examiner—Terrell McKinnon

(74) *Attorney, Agent, or Firm*—Nath & Associates PLLC;
Harold L. Novick; Marvin C. Berkowitz

(57) **ABSTRACT**

A network-type heat pipe device is disclosed, wherein the network-type heat pipe device comprises a heat dissipating unit with a network shape, a heat absorbing unit of any desired shape, and two single flexible capillary pipes connecting the heat absorbing unit with the heat dissipating unit. The working fluid filled in the heat pipe is of a predetermined quantity smaller than the internal volume of the heat pipe. The inside diameters of the capillary pipes of the network-shaped heat dissipating unit and the connecting capillary pipes are small enough such that the vapor and liquid segments of the working fluid may distribute therein by capillary effect. As the heat absorbing unit is heated, the mutual actions of the pushing or compression force generated due to the vaporization at the heat absorbing unit, the resisting force generated due to the vapor condensation at the heat dissipating unit, and the gravitational force generated due to the liquid segments in the vertical part of the capillary pipes in the heat dissipating unit and the connecting pipes cause a circulating flow for the working fluid to carry heat from the heat absorbing unit to the heat dissipating unit. The heat absorbing unit can be placed under the heat dissipating unit so as to enhance the gravitational force for circulating the working fluid in the single direction in the flow passage and to increase the heat transport from the heat absorbing unit to the heat dissipating unit.

19 Claims, 11 Drawing Sheets



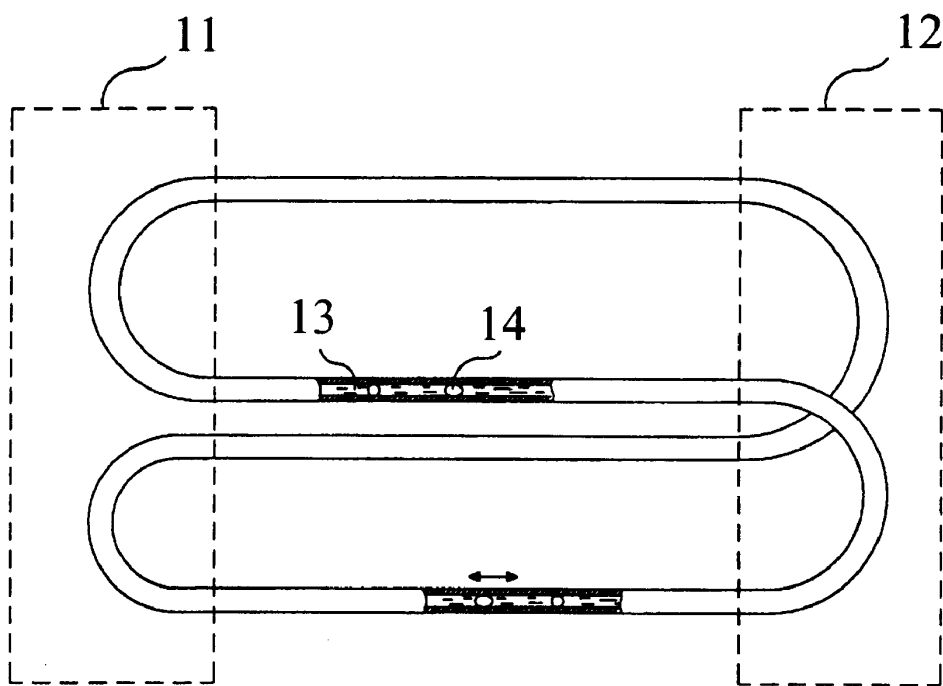


FIG. 1
(PRIOR ART)

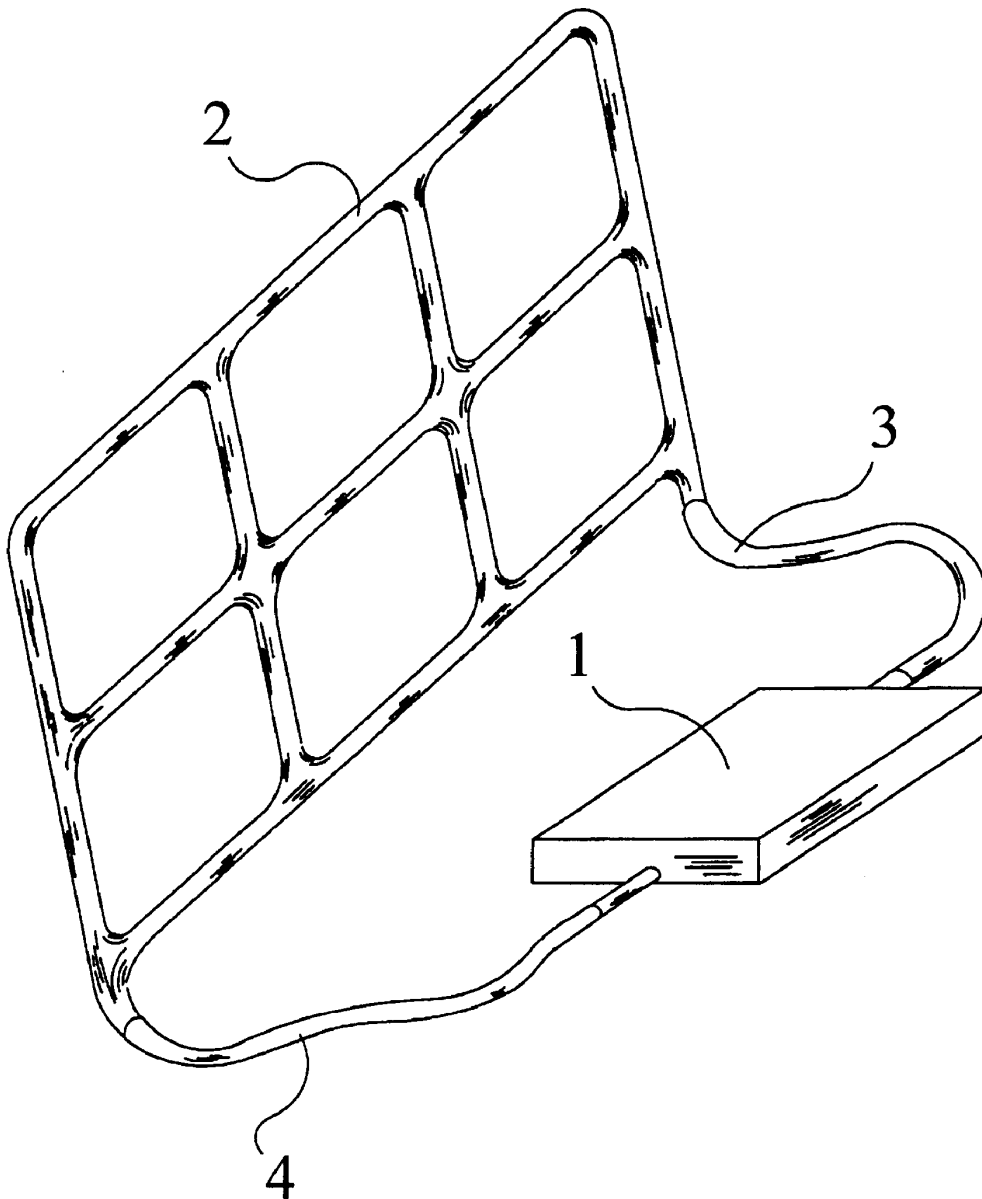


FIG. 2

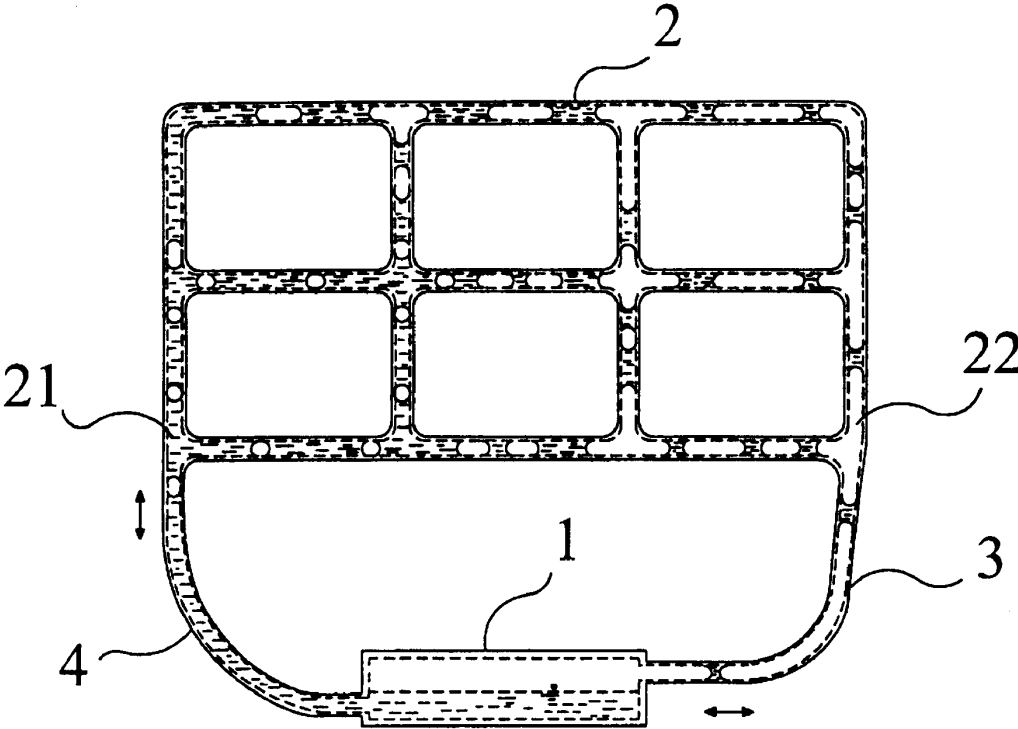


FIG.3

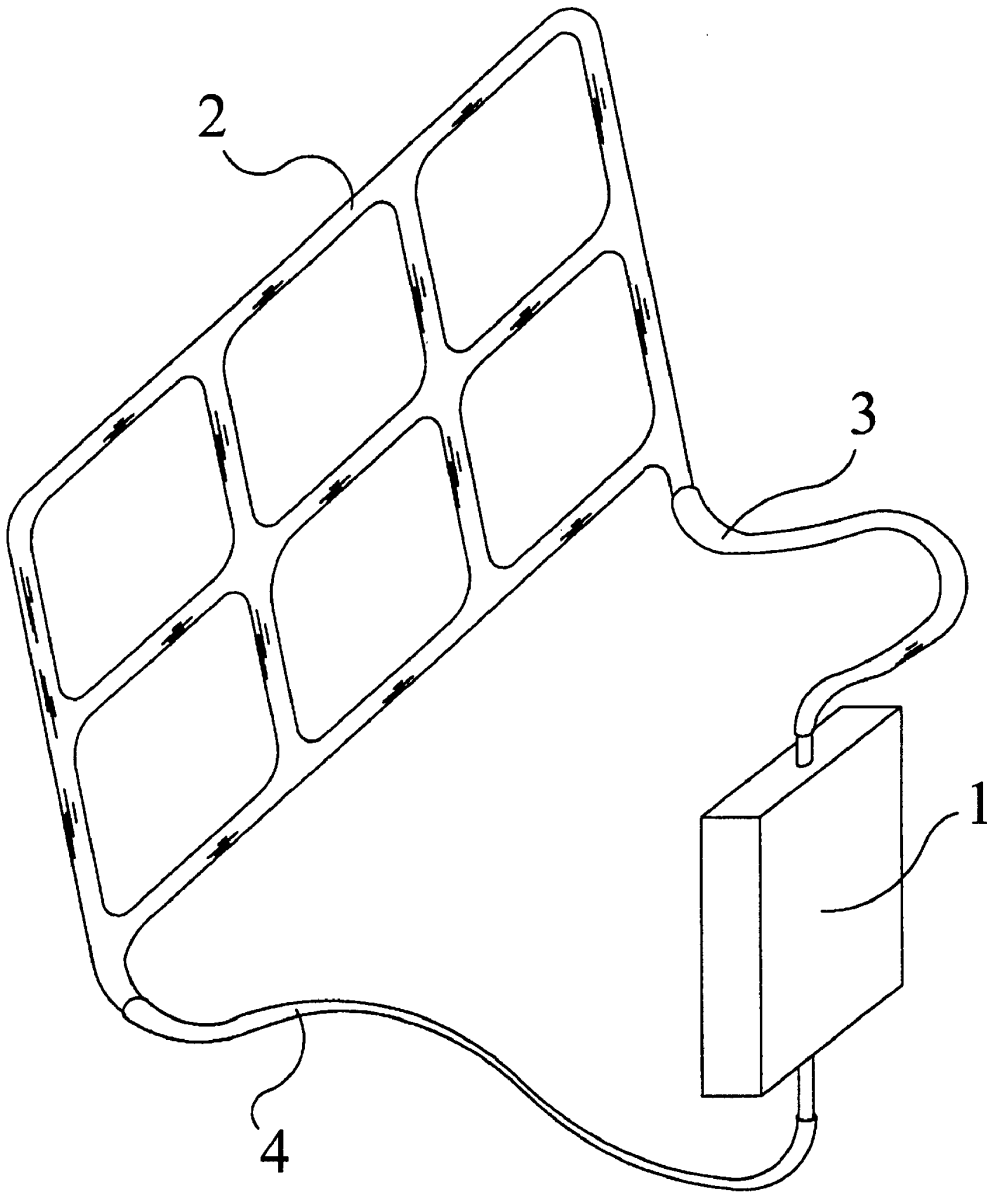


FIG. 4

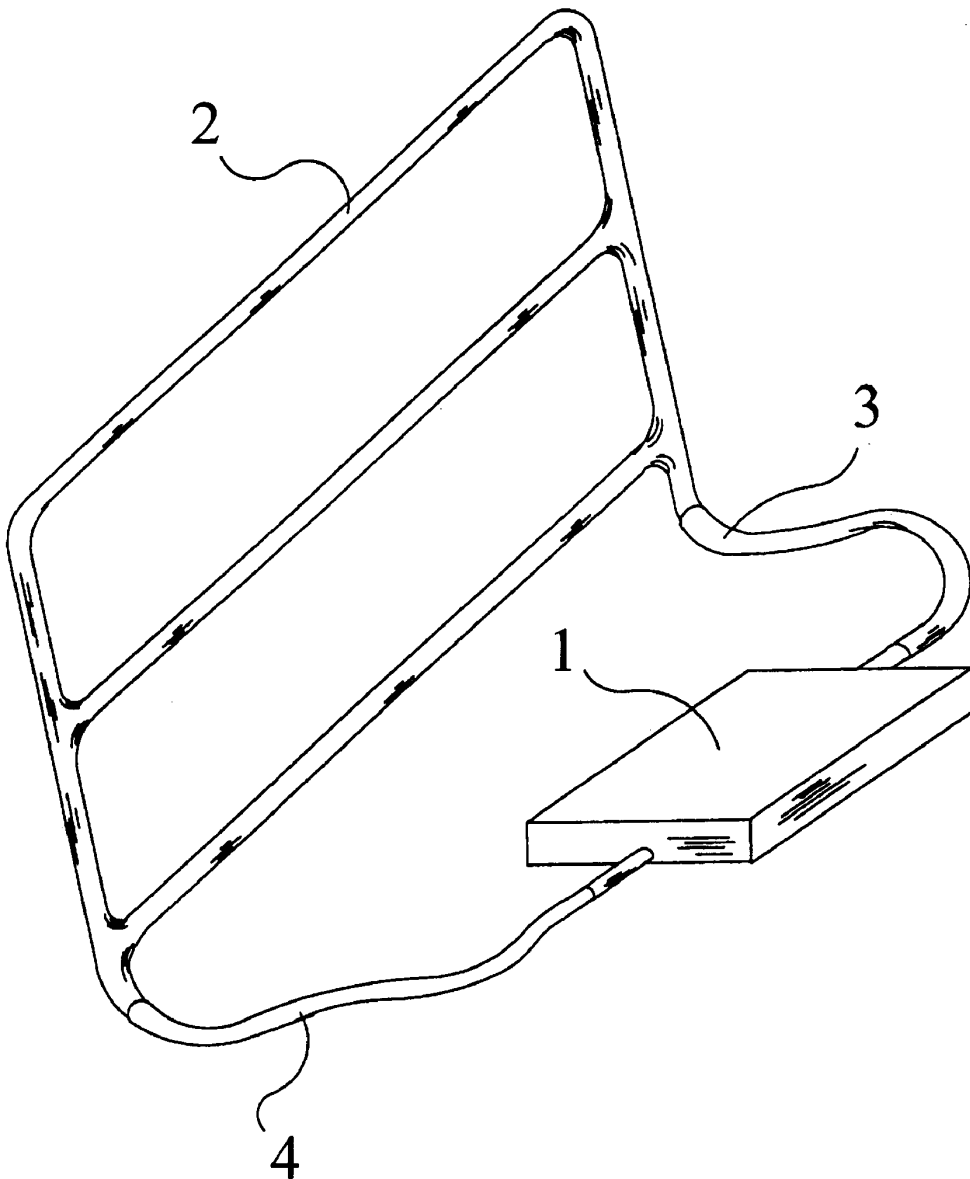


FIG. 5

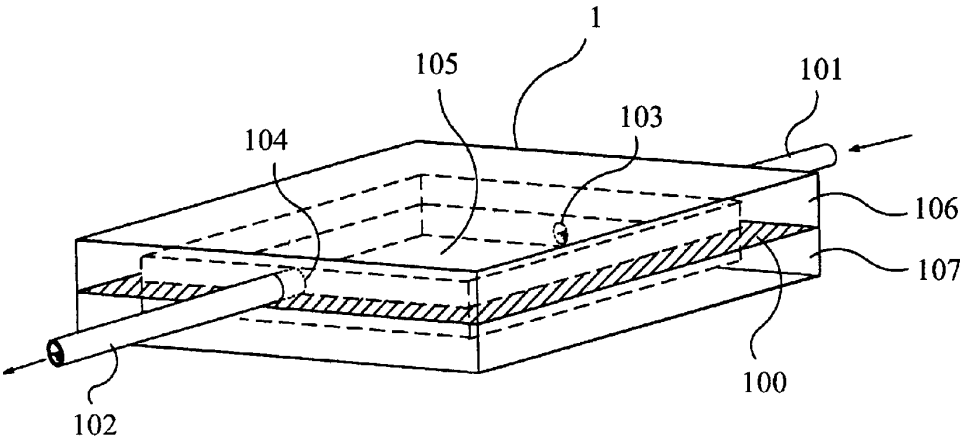


FIG. 6

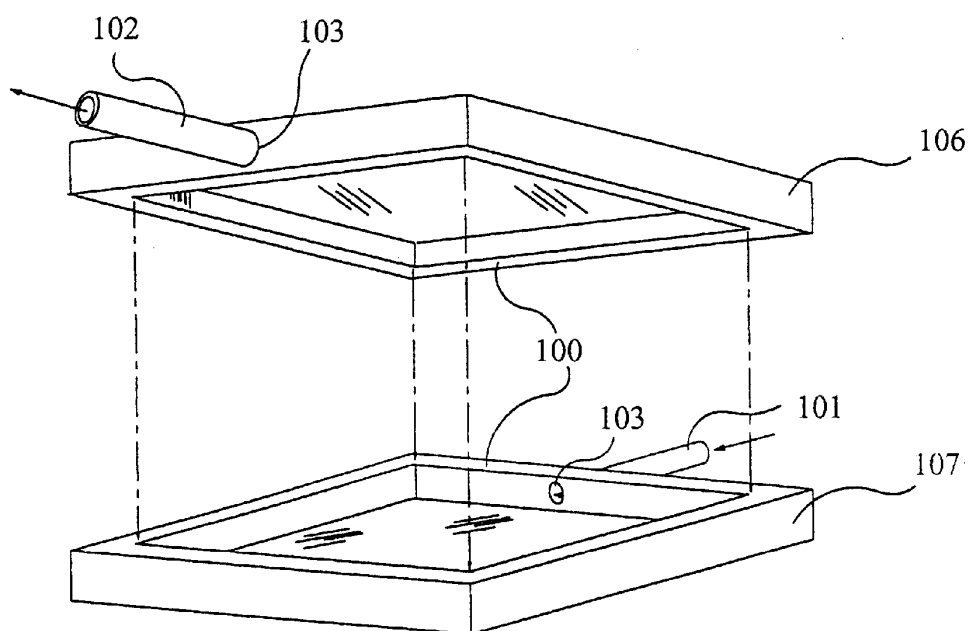


FIG. 7

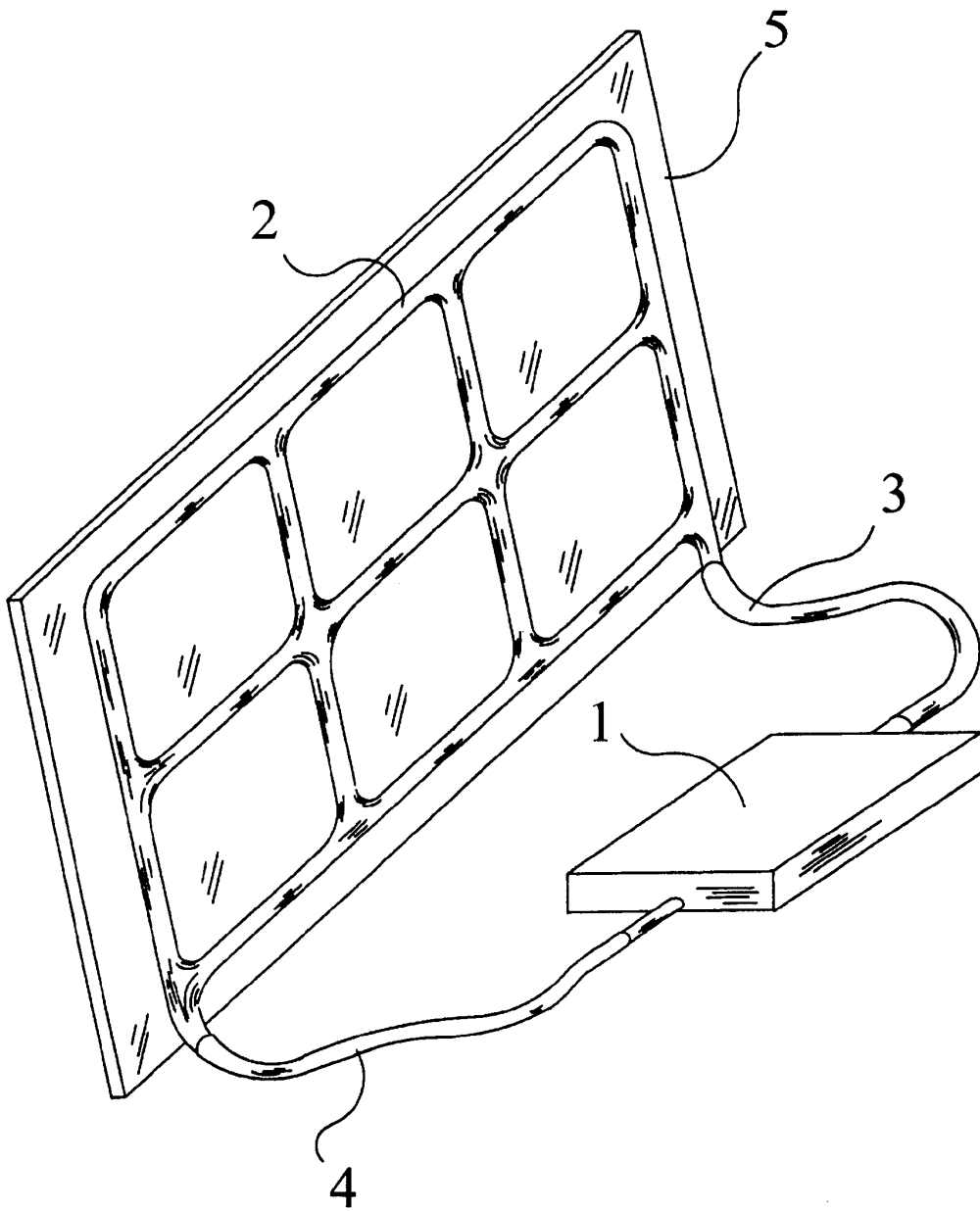


FIG. 8

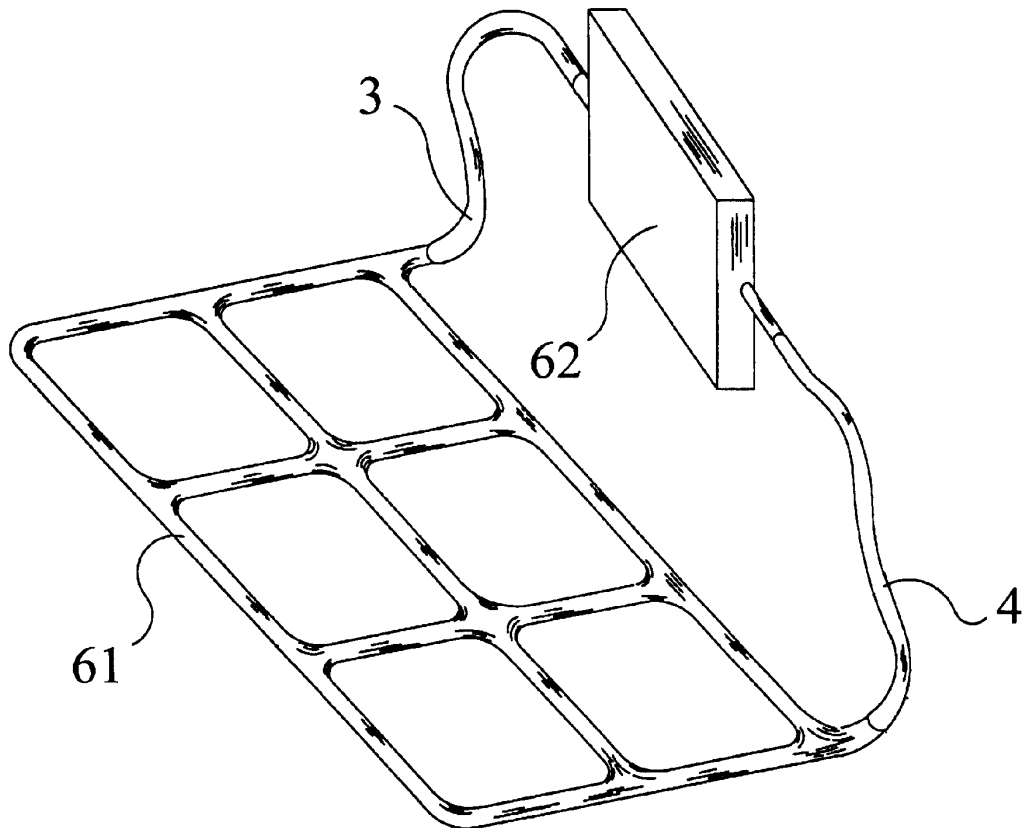


FIG. 9

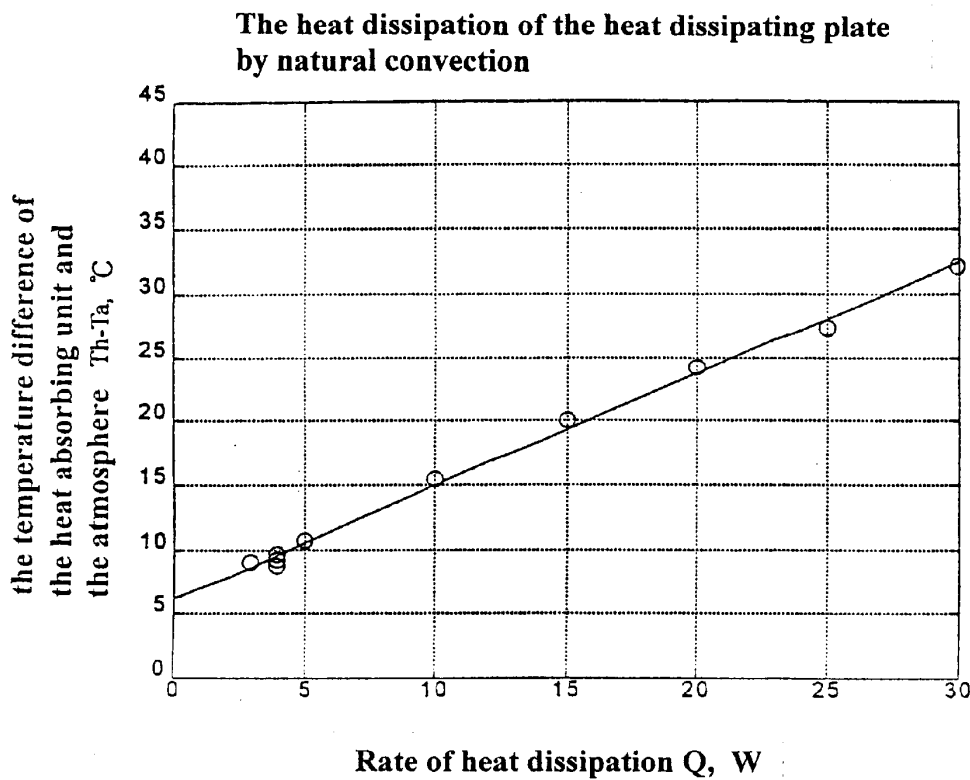


FIG. 10

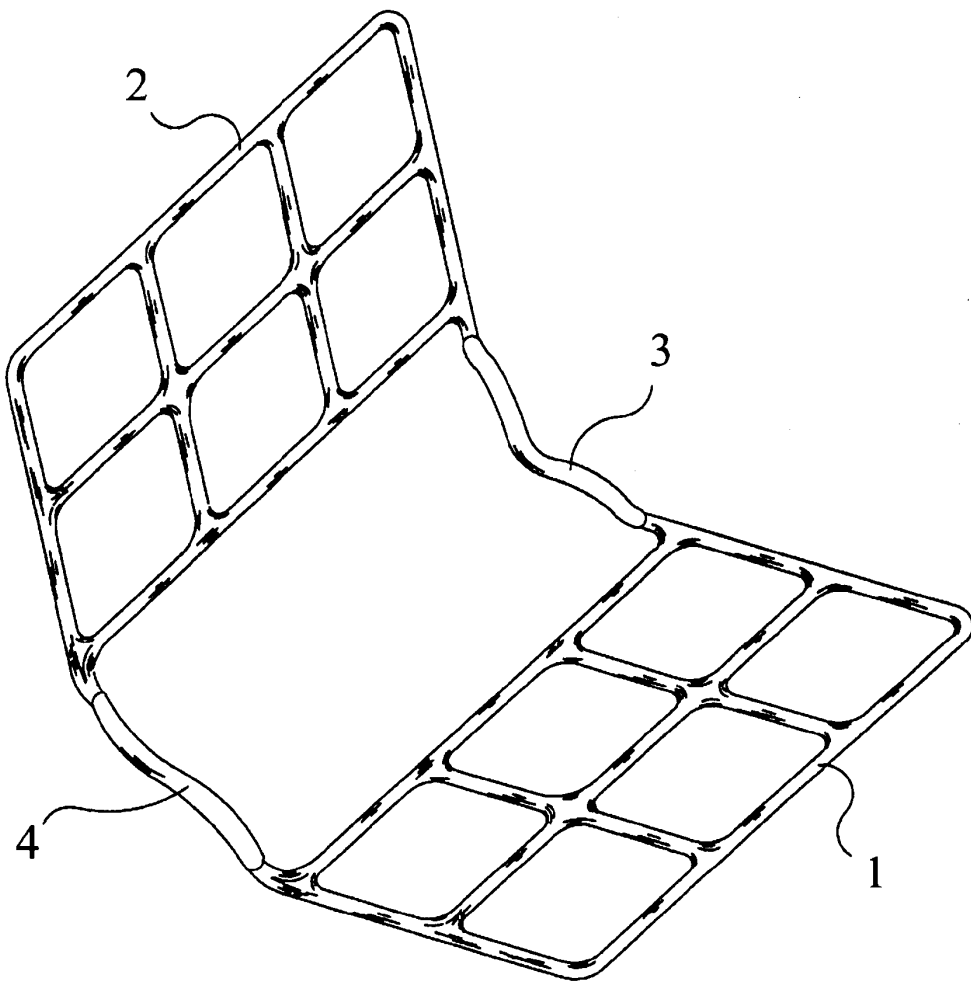


FIG.11

NETWORK-TYPE HEAT PIPE DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a heat transfer device of a network-type heat pipe, wherein the heat transfer is achieved by heat absorption from a heat source, evaporation and condensation of a working fluid fill the device, and the heat dissipates into a heat sink. The capillary pipes forming the heat dissipating unit are made into a network shape, the heat absorbing unit may be constructed in any shape desired for absorbing the heat; and two single capillary pipes are used to connect the heat absorbing unit and the heat dissipating unit.

2. Description of the Prior Art

The conventional heat transfer device of heat a pipe is formed by a pipe, a capillary structure or wick, and a working fluid. In general, a pipes is made of a straight metal tube. The hollow capillary structure made of a porous medium adheres to the inner wall of the tube and forms a hollow channel for the vapor of a working fluid to pass through. The working fluid, such as alcohol, methyl alcohol or water, fills the heat pipe. When one end of the heat pipe (the evaporator) is heated, the liquid working fluid absorbs the heat and evaporates to form a vapor. The vapor then flows out from the capillary structure in the evaporator to another end of the heat pipe (the condenser). The vapor then condenses as a liquid and penetrates the capillary structure in the condenser, while the condensed heat dissipates outwards. The condensed liquid is transferred back to the evaporator through a capillary structure by capillary effect to repeat the process of heating and evaporating and complete a cycle. There are three main defects in the conventional heat pipe: (1) it is made of hard straight tubes so that it lacks flexibility in installation; (2) the use of a capillary structure or porous medium in a heat pipe causes additional cost and quality control problems; (3) the distance of heat transport is limited by the capillary structure.

In order to improve the defects of the aforementioned conventional heat pipe, in the prior art the heat pipe is made as a closed loop and the inner part of the loop has no capillary structure. The loop is mounted vertically with the evaporator at the lower part of a vertical leg and the condenser is mounted at the upper part of another vertical leg. A working fluid, such as alcohol, methyl alcohol or water, fills the loop. When the evaporator is heated, the working fluid absorbs the heat and vaporizes to form a vapor. The vapor then flows to the condenser at the upper part of another vertical leg and condenses as liquid. The condensation heat dissipates outwards to achieve the heat transport, while the condensed liquid flows back to the evaporator by the gravitational force to complete a flow cycle. This kind of heat pipe is call as a "thermosyphon-loop heat pipe", the major defect of which is that the condenser and the evaporator are generally installed on a vertical plane with a short horizontal distance between them so as to minimize the frictional force of the working fluid flowing through the connecting tubes between the two legs.

In order to improve the defects of the conventional heat pipes, in U.S. Pat. No. 4,921,041 (1990) and 5,219,020 (1993), filed by Akachi, Japan, the aforementioned single-loop thermosyphon heat pipe is designed as a multiple-loop capillary heat pipe which is connected in a series to a bundle of parallel capillary pipes. The two ends of the heat pipe are interconnected to form a closed loop. The inner part of the pipe is empty (referring to FIG. 1). An evaporating unit (11)

of the multiple-loop capillary heat pipe is on one side and a condensing unit (12) on another side. Heat is transported from the evaporating unit 11 via the condensing unit 12 to the heat sink. The pipe is a designed as capillary tube in order to provide capillary effect. The pipe is filled with working fluid (such as alcohol, methyl alcohol, freon or water) at an appropriate volume ratio. Before operation of the heat pipe, the liquid working fluid is distributed in segments along the multiple-loop heat pipe by capillary effect, and vapor segments fill in between the liquid segments.

As the evaporating unit is heated, the liquid absorbs heat and vaporizes. The vapor bubbles start to grow and the pressure increases so as to push the liquid and vapor segments to flow toward the lower temperature end (condensing unit). The condensation of the vapor in the condensing unit at a lower temperature lowers the pressure and further enhances the apressure difference between the two ends of the evaporating and condensing unit. Because of the inter-connection of the pipe, the motion of liquid and vapor segments in one section of the tube toward the condenser also leads the motion of liquid and vapor segments in the next pipe section toward the high temperature end (evaporator) in the next section. This works as a restoring force. The interaction between the driving force and the restoring force leads to oscillation of the liquid and vapor segments in the axial direction. Therefore, this kind of heat pipe is called a "Pulsing heat pipe" or a "Capillary loop heat pipe". The frequency and amplitude of the oscillation are dependent on heat flow and mass fraction of the liquid in the pipe. There are two defects in this heat pipe: (1) the manufacturing of the capillary loop heat pipe with at least three pipe turns, or several tens or hundreds of turns is difficult and, in particular, the connection between the evaporating unit and the condensing unit is not easy; (2) the whole length of the capillary loop heat pipe must be made from a single capillary tube in order to form a single closed loop (with multiple turns). The design flexibility in practical application is therefore confined.

SUMMARY OF THE INVENTION

Accordingly, the object of the present invention is to provide a heat transfer device using network-shaped capillary pipes, wherein the heat absorbing unit may be any desired shape; The heat dissipating unit and the heat absorbing unit are connected by two single capillary pipes (one inlet and one outlet), therefore, it may be easily manufactured. A condensable working fluid fills the device.

According to the main goal of the present invention, it provides a network-type heat pipe device using capillary pipe, the heat transport is achieved by the heat absorption from a heat source in the heat absorbing unit, vaporization and condensation of a working fluid, and heat dissipation to a heat sink in the heat dissipating unit. The capillary pipes forming the heat dissipating unit are formed in a network shape. The heat absorbing unit may be formed in any desired shape for easy mounting to a heat source.

According to the aforementioned concept the inner part of the heat absorbing unit may be as an empty space in any desired shape so that the working fluid may flow therewith, and two single capillary pipes are used to connect the heat absorbing unit and the heat dissipating unit in each inlet and outlet. The heat absorbing unit can be installed at a position below the heat dissipating unit for better performance.

According to the above concept, a working fluid (such as alcohol, methyl alcohol, Freon, or water, etc.) is filled in the

3

heat absorbing unit, the heat dissipating unit and the connecting capillary pipes. Before operation, the capillary effect causes the working fluid to form as piece-wise liquid segments along the pipes, and vapor segments fill in between the liquid segments.

After startup, the liquid working fluid in the heat absorbing unit absorbs heat from a heat source and evaporates to form a pressurized vapor to flow out and compress the vapor segments (or bubbles) in the network-type capillary pipes of the heat dissipating unit. The compression of the vertical vapor segments in the capillary network of the heat dissipating unit causes an increase in the net gravitational force and the liquid flows down and back to the heat absorbing unit. The liquid in the heat absorbing unit continues to vaporize, and the vapor flows to the heat dissipating unit wherein the vapor condenses as liquid. The vaporized vapor in the heat absorbing unit also pushes the vapor bubbles and liquid segments within the network pipes of the heat dissipating unit along a direction, while the vapor segments in the heat dissipating unit condense due to the heat dissipation to heat sink. The vapor pushing force from the heat absorbing unit and the vapor condensation makes the vertical liquid segments merge together downstream and induces a net gravitational force for the liquid to flow back to the heat absorbing unit so as to complete a flow cycle. Heat is then absorbed at the heat absorbing unit and released at the heat dissipating unit.

During the startup or transient period, some liquid segments may exist inside the connecting pipe for the outflow from the heat absorbing unit to the heat dissipating unit. The vaporized vapor in the heat absorbing unit pushes the vapor and liquid segments in the connecting pipe toward the heat dissipating unit. The vertical liquid segments in the outflow pipe thus act as a resisting force to the net gravitational force for the liquid flow back to the heat absorbing unit through the inflow connecting pipe. The condensation of the vapor in the heat dissipating unit at a lower temperature causes a lower pressure and further enhances the pressure difference for the flow from the heat absorbing unit to the heat dissipating unit, but it in turn reduces the downward force for the liquid back flow to the heat absorbing unit. Therefore, the vapor and liquid of the working fluid will form a pulsating motion following the interaction of the evaporating pressure by heating, the lower vapor pressure force by vapor condensation, and the resisting force by the vertical liquid segments in the outflow of the heat absorbing unit. The liquid segments within the connecting pipe for the outflow of the heat absorbing unit will gradually flow into the horizontal part of the network pipe in the heat dissipating section. After the liquid segment within the connecting pipe for the outflow of the heat absorbing unit have been cleared up, a constant net gravitational force will be built and a steady flow along one direction will form. The process finally comes to a steady state and heat is transported steadily from the heat absorbing unit to the heat dissipating unit.

The present invention will be better understood and its numerous objects and advantages will become apparent to those skilled in the art by making reference to the attached drawings, described below.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 shows the structure of the capillary loop heat pipe device in the prior art.

FIG. 2 shows the structure of the network-shape heat pipe device of the present invention.

4

FIG. 3 is a cross section view of the network-shape heat pipe device of the present invention.

FIG. 4 is the structure of the heat absorbing unit of the present invention at a different orientation.

FIG. 5 is the network-shape capillary pipe of the heat dissipating unit in the present invention, with a different network shape.

FIG. 6 shows the structure of the heat absorbing unit in the present invention.

FIG. 7 is an expanded view of the heat absorbing unit in the present invention.

FIG. 8 shows the structure of the heat dissipating unit, which is attached to a heat dissipating plate.

FIG. 9 shows the structures of the heat absorbing unit and the heat dissipating unit of the present invention.

FIG. 10 shows the test results of the present invention.

FIG. 11 shows the heat dissipating unit and the heat absorbing unit with the network-shape capillary pipe structure of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 2, the structural schematic view of the preferred embodiment of the present invention is shown, wherein the network-type heat pipe device of the present invention comprises: a heat absorbing unit (1), the inside of which may be formed as a desired space so that the working fluid will flow within, with only a single capillary pipe connected on inlet 3 and outlet 4 thereof; a heat dissipating unit (2) made from the capillary pipes, which is formed as a network shape; a single capillary pipe (3, 4) which links the heat dissipating unit 2 and the heat absorbing unit 1; and a working fluid (such as alcohol, methyl alcohol, water, etc.) which fills the heat absorbing unit 1 and the capillary pipes. The amount of working fluid is approximately equal to 30% to 60% of the total inside volume. Before operation, capillary effect causes the working fluid to form as piece-wise liquid segments (21) distributed along the pipes, and vapor segments (22) filling between the liquid segments 21.

Now referring to FIG. 3, the cross section view of FIG. 2 is shown. Also, according to the aspects of FIGS. 2 and 3, when the heat dissipating unit 2 is arranged above the heat absorbing unit 1 and after startup as the heat absorbing unit 1 is heated, the liquid working fluid absorbs heat and evaporates to form a pressurized vapor to flow out and compress the vapor segments (or bubbles) 22 in the network made of capillary pipes in the heat dissipating unit 2. The compression of the vertical vapor segments in the capillary network of the heat dissipating unit 2 causes an increase in the net gravitational force for the liquid to flow down to the heat absorbing unit 1. The liquid in the heat absorbing unit 1 continues to vaporize, and the vapor flows to the heat dissipating unit 2 wherein the vapor condenses as liquid. The vaporized vapor in the heat absorbing unit 1 also pushes the vapor bubbles 22 and liquid segments 21 within the network pipes of the heat dissipating unit 2 along a direction, while the vapor segments 22 in the heat dissipating unit 2 condense and heat is ejected to the heat sink. The vapor pushing force from the heat absorbing unit 1 and the vapor condensation in the heat dissipating unit 2 makes the vertical liquid segments merge together at downstream and induces a net gravitational force for the liquid to flow back to the heat absorbing unit 1 so as to complete a flow cycle. Heat is thereby absorbed at the heat absorbing unit 1 and released at the heat dissipating unit 2.

5

During the startup or transient period, some liquid segments 21 may exist inside the connecting pipe 3 for the outflow from the heat absorbing unit 1 to the heat dissipating unit 2. The vaporized vapor in the heat absorbing unit 1 pushes the vapor and liquid segments in the connecting pipe 3 toward the heat dissipating unit 2. The vertical liquid segments in the outflow pipe thus act as a resisting force to the net gravitational force for the liquid flow back to the heat absorbing unit 1 through the other connecting pipe 4. The condensation of the vapor in the heat dissipating unit 2 at a lower temperature causes a lower pressure and further enhances the pressure difference for the flow from the heat absorbing unit 1 to the heat dissipating unit 2, but it in turn reduces the downward force for the liquid back flow to the heat absorbing unit 1. Therefore, the vapor and liquid of the working fluid will form a pulsating motion following the interaction of the evaporating pressure by heating, the lower vapor pressure force by condensing, and the resisting force by the vertical liquid segments in the outflow of the heat absorbing unit. The liquid segments within the connecting pipe 3 for the outflow of the heat absorbing unit 1 will gradually flow into the horizontal part of the network pipe in the heat dissipating section 2. After the liquid segments within the connecting pipe 3 for the outflow of the heat absorbing unit 1 have been cleared up, a constant net gravitational force will be built and a steady flow along one direction will form. The process finally comes to steady and heat is transported steadily from the heat absorbing unit to the heat dissipating unit.

According to FIGS. 2 and 3, the heat dissipating unit 2 may be arranged on any orientation. The heat absorbing unit 1 may be arranged horizontally or vertically (referring to FIG. 4). The relative position of the heat dissipating unit 2 and the heat absorbing unit 1 may be arranged at will. However, as the heat dissipating unit 2 is arranged above the heat absorbing unit 1, the gravitational effect of the vertical liquid segments will enhance the heat pipe performance. Thus, a preferred heat transfer is achieved.

According to FIGS. 2 and 3, the heat dissipating unit 2 is made from capillary pipes and as a network shape, further it may be made as an inter-network shape. In addition, it may be simplified as a parallel-shape network, as shown in FIG. 5, for easier manufacturing.

According to FIGS. 2 and 3, the connecting capillary pipes (3, 4) may be made from a flexible metal, polymer, or macro-molecular material.

According to FIGS. 2 and 6, the inner part of the heat absorbing unit 1 may be made as an empty space (105) as required. The ports (103, 104) thereof connect to two capillary connectors (101, 102). The outlook shape of the heat absorbing unit 1 may be made as a flat box as shown in FIG. 6 so that it can be easily adhered to the heating body. The heat absorbing unit 1 includes an inlet connector 101, an outlet connector 102, an evaporating chamber 105, an inlet port 103, and an outlet port 104. In order to allow for easy manufacturing, the heat absorbing unit 1 may be designed with upper and lower halves (106 and 107), which are then joined together at a surface 100. The inlet connector 101 is installed on the lower half 107 for receiving the liquid working fluid flowing into the evaporating chamber 105 which is then evaporated by heating. The outlet connector 102 is installed on the upper half 106 for guiding the vapor to flow out of the evaporating chamber 105. The expanded view of the upper and lower halves (106 and 107) are shown in FIG. 7.

Referring to FIG. 8 again, according to FIGS. 2, 4, and 5, the heat dissipating unit 2 made from the network-shape

6

capillary pipe may be adhered on a heat dissipating plate 5 for enhancing the heat dissipating ability thereof.

According to FIGS. 2, 4, 5, and 8, the shapes of the heat absorbing unit 1 and the heat dissipating unit 2 may be interchanged. Referring to FIG. 9 again, the heat absorbing unit 61 can be made as a network-shape capillary pipe, while the heat dissipating unit 62 may be made as a flat box as shown in FIG. 6 with empty space inside so that it can be easily adhered to a heat sink. Two single capillary pipes (3, 4) are used to connect the heat dissipating unit 62 and the heat absorbing unit 61.

In order to verify the concept of the present invention, the inventor has fabricated a prototype of a "network-type heat pipe device" for testing according to the structure of FIG. 8. The heat absorbing unit 1 is designed according to the structure of FIG. 6, with dimensions 50 mm long, 50 mm wide, and 8 mm high. The structure of the heat dissipating unit 2 is shown in FIG. 8. The area of the heat dissipating plate 5 is 300 mm by 200 mm, and has an 80 degree tilt angle. The inside diameter of the network-shape capillary pipe of the heat dissipating unit 2 is 1.8 mm. The capillary pipes (3 and 4) linking the heat absorbing unit 1 and the heat dissipating unit 2 are made from polycarbonate (PC) tubes with an outside diameter 4 mm. A disk-type thin-film electric heater with 19 ohms resistance is adhered under the heat absorbing unit 1, which is heated by a DC power supply to simulate a heat source. A heat insulating material is installed under the electric heater and on the outside surface of the connecting capillary pipe (3, 4) for reducing the heat loss so that the heating rate of the electric heater is approximately equal to the heat absorption rate of the heat absorbing unit 1 or the heat dissipation rate (Q) of the heat dissipating plate 5. During testing, no fan is used to enhance the heat transfer of the heat dissipating plate 5. The heat is dissipated by natural convection to the ambient. The testing results are shown in FIG. 10 and Table 1, wherein the filling quantity of the working fluid is 50% of the total volume. Therein the temperature difference ($\Delta T = T_h - T_a$) is defined as the temperature difference between the heat absorbing unit 1 (T_h) and the temperature of the atmosphere (T_a). The definition of thermal resistance R is $(T_h - T_a)/Q$, which represents the resistance of the heat transfer from the heat absorbing unit 1 (or heat source) to the ambient. It is shown from FIG. 10 and Table 1, under the condition of natural convection for the heat dissipating plate 5, the network-shape heat pipe fabricated by the inverter can dissipate 30W for the temperature difference (ΔT) at 32° C., the thermal resistance R is 1.07° C./W. The performance is superior to the other means. If it is used for the heat dissipation of notebook computers, this is prior to the prior heat dissipating technology.

Referring to FIG. 11, both the heat absorbing unit 1 and the heat dissipating unit 2. can also be made of capillary pipes and as a network shape or parallel-type network (referring to FIG. 5) heat pipe device. The heat absorbing unit 1 and the heat dissipating unit 2 are linked by two single capillary pipes (3, 4). The network-shape capillary pipes of the heat absorbing unit 1 and the heat dissipating unit 2 may also be adhered on a plate for enhancing the heat transfer (referring to FIG. 8).

TABLE 1

heat absorption amount Q, W	temperature of heat absorbing unit Th, ° C.	temperature of atmosphere Ta, ° C.	temperature Th - Ta, ° C.	heat resis- tance (TH - Ta)/Q, R, ° C./W
30.0	61.2	29.2	32.0	1.07
25.0	56.6	29.3	27.3	1.09
20.0	53.6	29.4	24.2	1.21
15.0	49.6	29.6	20.0	1.33
10.0	45.1	29.7	15.4	1.54
5.0	40.1	29.4	10.7	2.14
3.9	40.8	32.0	8.8	2.26
2.9	40.9	31.8	9.1	3.14

The present invention can be widely used in the heat dissipation of heat generating bodies, such as in computer or electronic devices (CPU, IC chips, power supplies, optic disks, or hard disks), home appliances (refrigerators, air conditioners, dehumidifiers, solar energy collectors), or other products or processes requiring heat transport from one place to another.

Although a certain preferred embodiment of the present invention has been shown and described in detail, it should be understood that various changes and modifications may be made therein without departing from the scope of the appended claims.

What is claimed is:

1. A heat pipe device used in heat transport, comprising:
 - (a) a heat absorbing unit inside of which is a space of any shape for storing working fluid; the heat absorbing unit being used to absorb heat from a heat source, said heat absorbing unit having an inlet and an outlet;
 - (b) a heat dissipating unit formed by network-shape capillary pipes comprising a geometric shape defined by a capillary inlet header pipe having an inlet, a capillary outlet header pipe having an outlet, and a plurality of capillary cross-pipes connecting said inlet and outlet header pipes together to form a plurality of cells, each cell being circumferentially bounded on all sides by a capillary pipe, for releasing the heat transported from the heat absorbing unit to a heat sink;
 - (c) a first connecting capillary pipe connected between the outlet of the heat absorbing unit and the inlet of the inlet header pipe of the heat dissipating unit, and a second connecting capillary pipe connected between the outlet of the outlet header pipe of the heat dissipating unit and the inlet of the heat absorbing unit so as to form a closed loop, said first and second connecting capillary pipes each being made from an extensible metal or nonmetal material;
 - (d) a condensable working fluid filled in the heat absorbing unit, the heat dissipating unit, and the first and second connecting capillary pipes, wherein a quantity of the filled liquid is smaller than a total volume of inner spaces of the heat absorbing unit, the heat dissipating unit and the first and second connecting capillary pipes; and wherein
 - (e) said heat absorbing unit and said heat dissipating unit are disposed other than adjacent to each other.
2. The heat pipe device as claimed in claim 1, wherein the inner spaces of the heat absorbing unit, the heat dissipating unit and the connecting capillary pipe are linked so that the condensable working fluid is sealed within and may flow within.
3. The heat pipe device as claimed in claim 2, wherein the inside diameters of the capillary pipes of the network-shape

heat dissipating unit and the connecting capillary pipes are small enough such that the vapor and liquid segments of the working fluid may distribute therein by capillary effect, wherein as the heat absorbing unit is heated, the mutual actions of the pushing or compression force generated due to the vaporization at the heat absorbing unit, the resisting force generated due to the vapor condensation at the heat dissipating unit, and the gravitational force generated due to the liquid segments in the vertical part of the capillary pipes in the heat dissipating unit and the connecting pipes cause a circulating flow for the working fluid to carry heat from the heat absorbing unit to the heat dissipating unit.

4. The heat pipe device as claimed in claim 3, wherein the heat absorbing unit is installed under the heat dissipating unit so as to enhance the gravitational force for circulating the working fluid in a single direction in the flow passage and to increase the heat transport from the heat absorbing unit to the heat dissipating unit.

5. The heat pipe device as claimed in claims 3 or 4, wherein the heat dissipating unit is made of network-shape capillary pipes having at least two parallel rows of capillary pipes the inner part of which are connected with each other.

6. The heat pipe device as claimed in claim 3 or 4, wherein the network-shape capillary pipes in the heat dissipating unit is adhered on a plate for enhancing the heat transfer the heat sink.

7. The heat pipe device as claimed in claims 3 or 4, wherein the heat dissipating unit is made of network-shape capillary pipes having at least two parallel rows of capillary pipe, the inner part of which are connected with each other, and the network-shape capillary pipes are adhered on a plate for enhancing the heat transfer to the heat sink.

8. The heat pipe device as claimed in claims 3 or 4, wherein the heat absorbing unit may be made as a flat-box shape and includes an inlet port, an outlet port, an evaporating chamber, characterized in that:

the heat absorbing unit may be designed with upper and a lower halves, that are then joined together as a whole body;

the inlet port for the working fluid is installed on the lower half for receiving the liquid working fluid flowing into the evaporating chamber;

the outlet port is installed on the upper half for guiding the vapor to flow out of the evaporating chamber.

9. The heat pipe device as claimed in claim 1 wherein said cells defined by said network-shape capillary pipes are arranged in a plurality of rows and columns.

10. The heat pipe device as claimed in claim 1 wherein said network-shape capillary pipes comprise:

an upper cross-header pipe and a lower cross-header pipe, each of which is connected between said outlet and inlet header pipes; and

a plurality of interconnect pipes which interconnect said upper and lower cross-header pipes;

thereby forming said cells.

11. The heat pipe device as claimed in claim 10 and further comprising a further plurality of interconnect pipes which interconnect said first mentioned interconnect pipes; thereby forming a plurality of rows and columns of said cells.

12. The heat pipe device as claimed in claim 1 wherein said network-shape capillary pipes of said heat dissipating unit provide a plurality of network-type flow passages made from capillary pipes.

13. A heat pipe device used in heat transport, comprising:

- (a) a heat absorbing unit made of network-shape capillary pipes comprising a first geometric shape defined by a

9

first capillary inlet header pipe having an inlet, a first capillary outlet header pipe having an outlet, and a plurality of first capillary cross-pipes connecting said first inlet and first outlet header pipes together to form a first plurality of cells, each cell being circumferentially bounded on all sides by a first capillary pipe, the heat absorbing unit being used to absorb heat from a heat source;

- (b) a heat dissipating unit made of network-shape capillary pipes comprising a second geometric shape defined by a second capillary inlet header pipe having an inlet, a second capillary outlet header pipe having an outlet, and a second plurality of capillary cross-pipes connecting said second inlet and outlet header pipes together to form a second plurality of cells, each cell being circumferentially bounded on all sides by a second capillary pipe, for releasing heat to a heat sink;
- (c) a first connecting capillary pipes connected between the outlet of the outlet header pipe of the heat absorbing unit and the inlet of the inlet header pipe of the heat dissipating unit, and a second connecting capillary pipe connected between the outlet of the outlet header pipe of the heat dissipating unit and the inlet of the inlet header pipe of the heat absorbing unit so as to form a closed loop, said first and second connecting capillary pipes each being made from an extensible metal or nonmetal material;
- (d) a condensable working fluid filled within the heat absorbing unit, the heat dissipating unit, and the inner space of the first and second connecting capillary pipes, wherein a quantity of filled liquid is smaller than a total volume of inner spaces of the heat absorbing unit, the heat dissipating unit and the first and second connecting capillary pipes; and wherein
- (e) said heat absorbing unit and said heat dissipating unit are disposed other than adjacent to each other.

14. The heat pipe device as claimed in claim 13, wherein the inner spaces of the heat absorbing unit, the heat dissipating unit, and the connecting capillary pipe are linked so that the condensable working fluid is sealed within and may flow within.

10

15. The heat pipe device as claimed in claim 14, wherein the inside diameters of the network-shape capillary pipes in the heat dissipating unit and the heat absorbing unit and the connecting capillary pipes are small enough such that the vapor and liquid segments of the working fluid may distribute therein by capillary effect, so that as the heat absorbing unit is heated, the mutual actions of the pushing or compression force generated due to the vaporization at the heat absorbing unit, the resisting force generated due to the vapor condensation at the heat dissipating unit, and the gravitational force generated due to the liquid segments in the vertical part of the capillary pipes in the heat dissipating unit and the connecting pipes cause a circulating flow for the working fluid to carry heat from the heat absorbing unit to the heat dissipating unit.

16. The heat pipe device as claimed in claim 15, wherein the heat absorbing unit is installed under the heat dissipating unit so as to enhance the gravitational force for circulating the working fluid in the single direction in the flow passage and to increase the heat transport from the heat absorbing unit to the heat dissipating unit.

17. The heat pipe device as claimed in claim 15, wherein the heat dissipating unit and the heat absorbing unit are made of at least two parallel rows of capillary pipes corresponding inner parts of which are connected with each other.

18. The heat pipe device as claimed in claim 15, wherein the network-shape capillary pipes in the heat dissipating unit and the heat absorbing unit are adhered on a plate for enhancing the heat dissipation of the heat sink.

19. The heat pipe device as claimed in claim 15, wherein the heat dissipating unit and the heat absorbing unit are made of at least two parallel rows of capillary pipes corresponding inner parts of which are connected with each other, and the network-shape capillary pipes are adhered on a plate for enhancing the heat dissipation of the heat sink.

* * * * *



Applied Thermal Engineering

Volume 17, Issue 6, June 1997, Pages 561-568

Application of heat pipe heat exchangers to humidity control in air-conditioning systems

Xiao Ping Wu, Peter Johnson, Aliakbar Akbarzadeh

Show more

[https://doi.org/10.1016/S1359-4311\(96\)00058-0](https://doi.org/10.1016/S1359-4311(96)00058-0)

[Get rights and content](#)

Abstract

Relative humidity control in air-conditioning systems is an important aspect of the maintenance of good indoor air quality. However, considerable reheat energy is needed to control relative humidity using conventional reheating coils. For improved energy efficiency a **thermosyphon heat pipe** heat exchanger is under investigation using a Hilton Air-Conditioning Laboratory Unit in RMIT. The study involves aspects of the heat exchanger, including temperature effectiveness, capability of energy recovery and relative humidity control of delivered air. It is observed that this type of heat exchanger can be an advantageous replacement for conventional reheat coils, resulting in energy saving and enhancing the cooling capability of the cooling coils with little or no external energy needed.



Previous article

Next article



Keywords

Heat pipe heat exchanger; relative humidity; dehumidification; heat recovery

Choose an option to locate/access this article:

Check if you have access through your login credentials or your institution.

Check Access

or

Purchase

Rent at DeepDyve

[Recommended articles](#)

[Citing articles \(60\)](#)

Copyright © 1997 Published by Elsevier Ltd.

ELSEVIER

[About ScienceDirect](#) [Remote access](#) [Shopping cart](#) [Contact and support](#)
[Terms and conditions](#) [Privacy policy](#)

Cookies are used by this site. For more information, visit the [cookies page](#).

Copyright © 2018 Elsevier B.V. or its licensors or contributors. ScienceDirect® is a registered trademark of Elsevier B.V.

 RELX Group™

[Sign on](#)[SAO/NASA ADS](#) [Physics Abstract Service](#)

- [Find Similar Abstracts](#) (with [default settings below](#))
- [Reads History](#)
- [Translate This Page](#)

Title: Heat transfer characteristics of two-phase thermosyphon heat pipe. I - Boiling heat transfer correlation in heating section

Authors: [Kaminaga, Fumito](#) ; [Okamoto, Yoshizo](#)

Publication: Japan Society of Mechanical Engineers, Transactions B (ISSN 0387-5016), vol. 58, no. 552, p. 2543-2549.

Publication Date: 08/1992

Category: Fluid Mechanics and Heat Transfer

Origin: [STI](#)

NASA/STI Keywords: Heat Transfer Coefficients, Nucleate Boiling, Thermosiphons, Two Phase Flow, Heat Pipes, Pressure Distribution, Working Fluids

Bibliographic Code: [1992JSMET..58.2543K](#)

Abstract

A correlation for the boiling heat transfer coefficient in the heating section of a two-phase thermosyphon heat pipe is developed in comparison with experimental data. The experiments are conducted for a vertically oriented thermosyphon pipe using three kinds of working fluid, water, Feron R 113, and ethanol, at a wide pressure range of 0.1 to 20 bar and a fill charge rate of 0.3 to 0.9. The correlation is obtained by modification of Kutateladze's nucleate boiling correlation in terms of an additional two parameters, the density ratio of liquid and vapor and the surface roughness. The correlation is shown to be in good agreement with the experimental data at a system pressure above 1 bar. The experiments also indicate that the adiabatic wall temperature is less than the saturation temperature corresponding to the system pressure in the pipe.

[Bibtex entry for this abstract](#) [Preferred format for this abstract](#) (see [Preferences](#))

Add this article to private library

Remove from private library

Submit corrections to this record

View record in the new ADS

Find Similar Abstracts:

Use: ☐ Authors
☒ Title
☒ Keywords (in text query field)
☒ Abstract Text

Return: ☒ Query Results

Return items starting with number

☐ Query Form

Database: ☐ Astronomy

☒ Physics

☐ arXiv e-prints

Send Query

Reset

- [54] THERMOSYPHON HEAT PIPE HOT WATER APPLIANCE
- [75] Inventor: Ying-Nien Yu, Marina del Rey, Calif.
- [73] Assignee: Ying Mfg. Corp., Gardena, Calif.
- [21] Appl. No.: 333,424
- [22] Filed: Dec. 20, 1983
- [51] Int. Cl.³ F24J 3/02
- [52] U.S. Cl. 126/435; 126/433; 126/437
- [58] Field of Search 126/426, 433, 434, 400, 126/448, 435, 436, 437, 450, 417; 165/104.22, 104.24

[56] References Cited

U.S. PATENT DOCUMENTS

1,119,063	Burnap.	
2,575,478	Wilson.	
2,911,513	11/1959 MacCracken	126/400
3,859,980	1/1975 Crawford	126/426

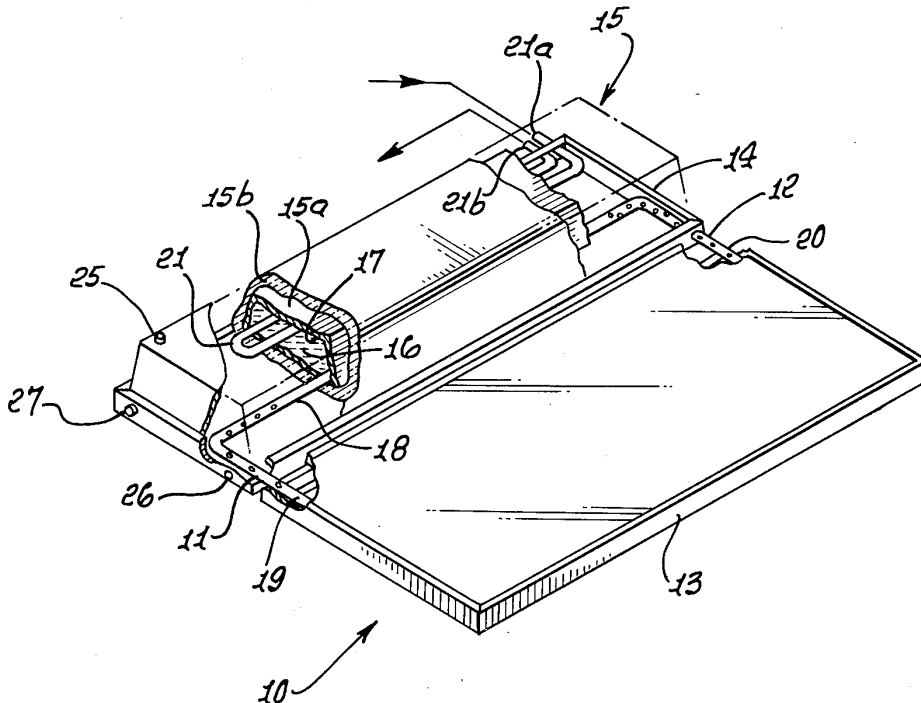
3,875,926	4/1975 Frank	126/433
3,943,911	3/1976 Yu	126/445
3,987,782	10/1976 Meier, Jr.	126/434
4,084,578	4/1978 Ishibashi	126/434
4,084,579	4/1978 Yu	126/432
4,116,222	9/1978 Seifried	126/435
4,248,291	2/1981 Jarmul	126/436
4,270,523	6/1981 Van Heel	126/435
4,313,424	2/1982 Schreyer et al.	126/433

Primary Examiner—James C. Yeung
Attorney, Agent, or Firm—William W. Haeffliger

[57] ABSTRACT

A thermosyphon heat pipe hot water appliance combines a solar collector with a heat reservoir wherein fluid vaporized in the collector transfers latent heat to reservoir fluid, for re-transfer to fluid such as water supplied by city reservoirs, or from municipal mains.

10 Claims, 4 Drawing Figures



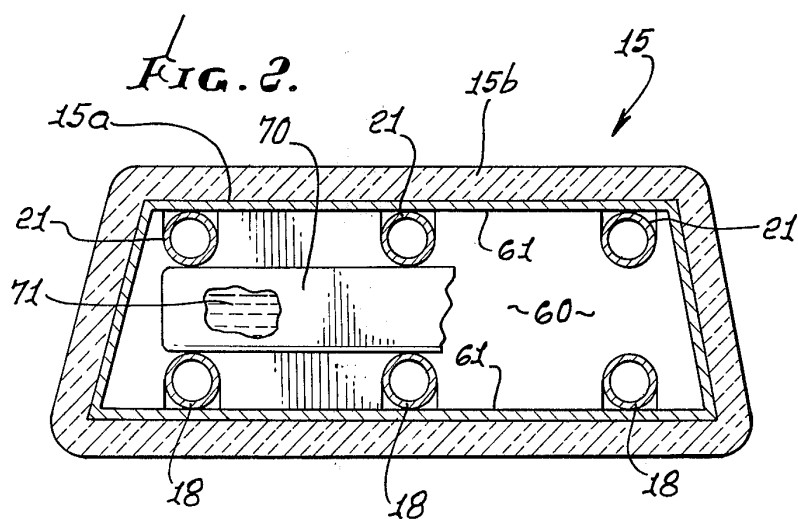
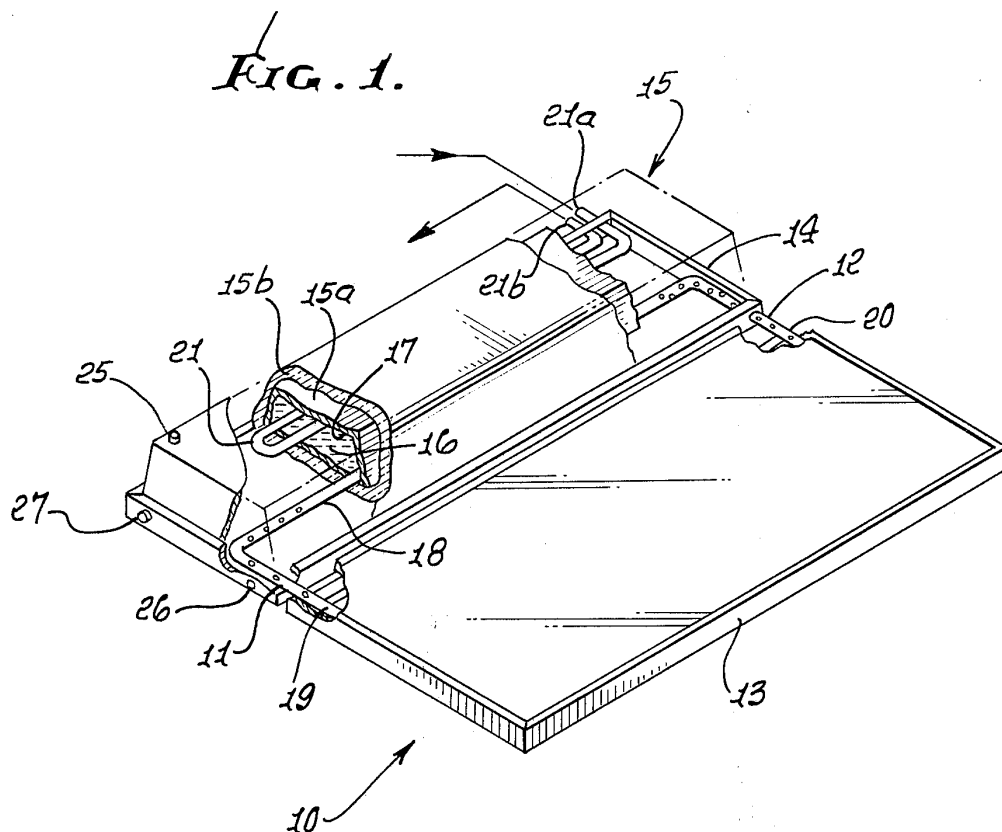


FIG. 3.

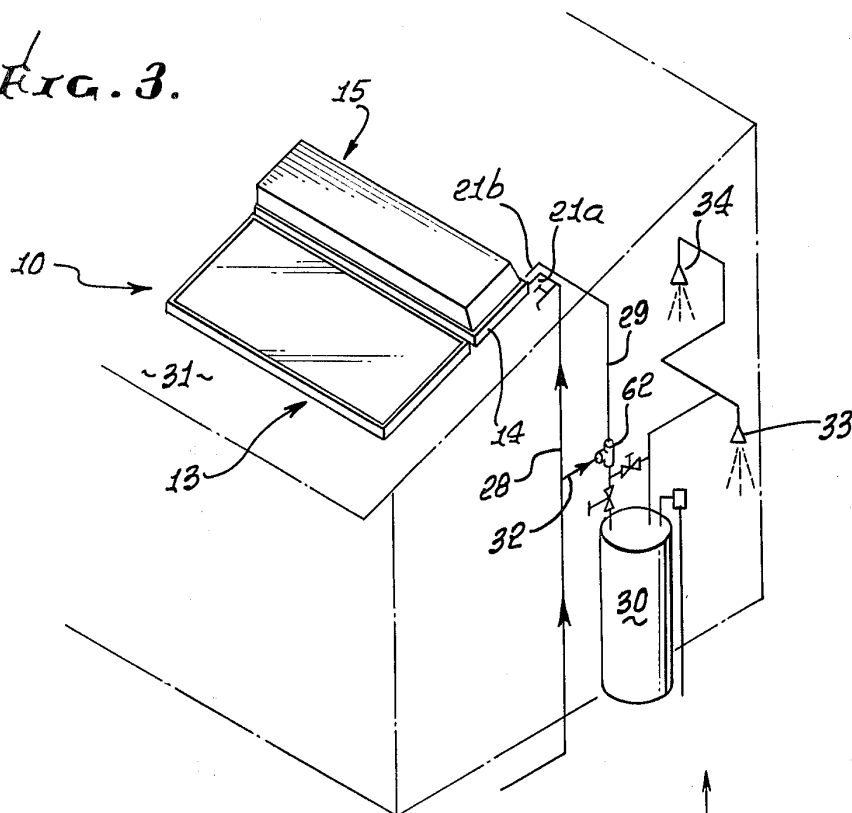
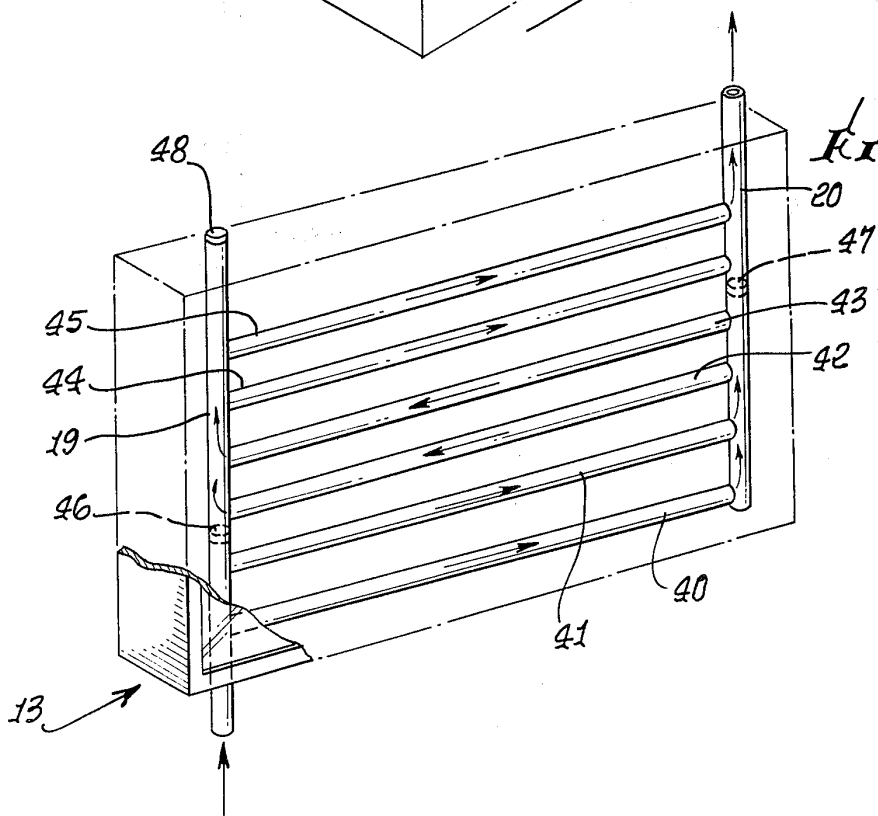


FIG. 4.



THERMOSYPHON HEAT PIPE HOT WATER APPLIANCE

BACKGROUND OF THE INVENTION

This invention relates generally to appliances for heating liquid such as water; more particularly the invention concerns a combination solar collector and heat reservoir wherein fluid vaporized in the collector transfers latent heat to reservoir fluid, for re-transfer to fluid such as water supplied from city reservoirs.

There is a need for extending the heating effectiveness of solar collectors during periods such as night time, and temporarily cloudy weather conditions, wherein the solar collector is not receiving solar radiation. In particular, there is a need for a heat reservoir of lightweight compact construction, which can be mounted on a dwelling roof along with the collector. Further, there is a need for such equipment wherein the reservoir and collector are characterized by high operating efficiency, including high heat transfer efficiency, low weight, and small volume.

SUMMARY OF THE INVENTION

It is a major object of the invention to provide method and apparatus meeting the above need. Basically, and in its apparatus respects, the fluid heating assembly of the invention comprises:

- (a) a solar collector having an inlet for a first fluid to be heated, and an outlet for the solar heated fluid,
- (b) a tank for containing a heat transfer second fluid,
- (c) first ducting in the tank in communication with said collector outlet to receive said heated first fluid and to transfer heat therefrom to the second fluid in the tank,
- (d) and second ducting in the tank for passing third fluid into and out of the tank, and to transfer heat from the second fluid in the tank to the third fluid in the second ducting.

Typically, frameworks for the collector and tank are integrally connected enabling mounting the assembly as a unit on a roof of a dwelling, with the tank at a higher level than the collector; and the collector is operated to vaporize the first fluid (such as Freon, for example) so that latent heat is efficiently transferred to the second fluid in the tank, at a high temperature.

In its method aspects, the invention includes the steps:

- (a) causing solar radiation to heat a first fluid,
- (b) passing the heated first fluid in heat transfer relation with a body of second fluid for heating the second fluid,
- (c) and passing a third fluid stream in heat exchange relation with the body of second fluid for transferring heat from said body to said third fluid stream.

The (a) step typically includes vaporizing the first fluid by solar heating thereof, and the (b) step includes condensing the first fluid vapor to transfer latent heat to the body of second fluid.

These and other objects and advantages of the invention, as well as the details of an illustrative embodiment, will be more fully understood from the following description and drawings, in which:

DRAWING DESCRIPTION

FIG. 1 is a perspective view partly broken away, showing one form of fluid heater assembly incorporating the invention;

FIG. 2 is a cross section through a tank showing a modified construction;

FIG. 3 is a system perspective; and

FIG. 4 is a perspective showing details of a solar collector.

DETAILED DESCRIPTION

In FIG. 1, a solar collector 10 has an inlet (defined by duct 11) for a first fluid to be heated by solar radiation, and an outlet (defined by duct 12) for the solar heated fluid. The collector is shown as carried by a first rectangular frame 13.

A second and smaller rectangular frame 14 carries a tank 15 for containing a heat transfer second fluid 16. The tank is shown as including a metallic liner 15a, and insulation 15b enclosing the lining. The insulation may for example consist of styrofoam, and the metal liner of heat conductive metal such as copper or copper alloy.

First ducting in the tank interior 17 communicates with the solar collector to receive the heated first fluid and transfer heat therefrom to the second fluid body 16 in the tank interior. That ducting is shown for example at 18 in endwise series communication with inlet 11 and outlet 12. First ducting 18 may be integral with header pipes 19 and 20 in the solar collector, and may advantageously contain Freon to be vaporized in the collector and to be condensed in duct 18, to release latent heat transferred to the body of liquid 16 in the tank.

Second ducting 21 also extends in the tank, in the heated body of liquid 16, for passing third fluid (as for example liquid such as water) into and out of the tank via ports 21a and 21b. The second ducting 21 is heated by the water body 16 and transfers heat to the third fluid flowing in that second ducting 21. Accordingly, the third fluid, such as water to be used in the home, is efficiently heated by the hot liquid reservoir 16, which acts as a heat source during the night or cloudy weather when the solar collector itself is not being heated by the sun's rays; also, the heat storage capacity is enhanced due to latent heat of vaporization release to the water body 16 upon condensation of Freon in the duct 18. All ducts in the tank may consist of copper, or other good heat conductive metal, for efficient heat exchange.

FIG. 2 shows a modified tank interior construction, wherein heat conductive metallic structure such as webbing 60 contacts (or is connected with) the ducts 18 and 21, as well as the tank walls at 61, to transfer heat from the tank wall and/or from duct 18, by conduction, to duct 21, for increasing the heat transfer efficiency. Fluid 16 may consist of water, and first fluid in duct 18 may consist of Freon or water. In addition, a container 70 may be located between ducts 18 and 21, and in contact therewith. Within the container is a phase change material acting to store thermal energy in its melting phase change. Examples of such materials are paraffin, and magnesium salts, and melting temperatures are for example between 90° and 140° F. Also, the container and its contents transfer heat by conduction from ducts 18 to ducts 21. Container 70 may consist of a plastic bladder. During times of no solar radiation, latent heat is transferred from the material 71 to the second fluid 16, for re-transfer to third fluid in ducting 21.

3

FIG. 1 also shows tank 15 having a fill port 25 and a drain port 26. A safety vent appears at 27.

FIG. 3 shows the ports 21a and 21b connected via lines 28 and 29 with a communicating water source and with a hot water storage tank 30. The frames 13 and 14 for the solar collector 10 and tank 15 are interconnected and mounted on a dwelling inclined roof 31, as shown. A shunt line 32 from line 28 connects to a mixing valve 62 in line 29, to allow controllable mixing of hot and cold water feed to tank 30. The latter supplies water outlets 33 and 34 in the dwelling.

FIG. 4 shows a solar collector interior construction with first and second header pipes 19 and 20. Parallel branch pipes 40-45 are connected between the two headers. Plugs 46-48 in the headers, as shown, cause serpentine flow via at least two branch pipes for each traverse between the headers. Thus, plug 46 causes transfer flow via two branches 40 and 41 to header 20; plug 47 in header 20 causes traverse flow via branches 42 and 43 back to header 19, and plug 48 in header 19 causes traverse flow in branches 44 and 45 back to header 20, for discharge to the tank 15. Holes in plugs 46 and 47 may pass a small flow of fluid.

The construction of the solar collector may otherwise follow that described in my U.S. Pat. No. 4,084,579. The headers and branches may be coated with "chrome velvet", a black compound imparting high solar radiation absorptivity, and low infra-red wave emissivity.

In operation, whenever there is sufficient solar irradiation, Freon boils and changes from liquid to vapor phases. This phenomenon is known as boiling liquid heat transfer by latent heat, or a "heat-pipe" principle. Test data indicates that the boiling liquid heat transfer in solar collector panels, as compared to liquid flow process heat transfer in the same collector, is higher by up to 35 percent. The saturated Freon vapor rises to the storage tank and condenses as it transfers the solar energy to the storage reservoir. The condensed and liquefied Freon returns to the bottom of the collector. The process repeats so long as there is sufficient solar irradiation. Because of the highly efficient heat exchanger design, less than 5 percent of losses are experienced through the transfer of heat from the collector to the storage tank. Therefore, a net gain of 20 percent is realized with a boiling liquid transfer process, as compared to the conventional liquid flow heat transfer process in solar collectors.

The second heat exchanger transfer the cold, incoming city water to hot water before it enters the conventional backup water heater. Once again, because of the unique "low loss" design features of the heat exchanger, the leaving hot water is at practically the same temperature as the hot water within the storage tank.

In the event of excess pressure build-up in the second fluid 16, the safety vent or valve at 27 will open to relieve the excess pressure.

The invention is particularly characterized by low weight, low volume, or high heat capacity, as compared with prior systems, as well as by safe guarded "liquid-to-liquid-to-liquid" heat transfer to potable water in ducts 21.

From the foregoing it will be seen that an important purpose of this invention is to achieve an efficient heat transfer process with the three-fluid arrangement. Most of the local health authorities in the United States require two-walled separation of city water and other transfer fluids to reduce the hazard of cross connection.

4

The conventional two-walled heat exchangers available in the market are inefficient because of an air gap separating the two walls. The air gap is a means of visible leak detection. The present invention provides a three-fluid system. The second fluid is contained in an atmospherically vented bladder or tank such that leakage of the first fluid or the second fluid will escape through the second fluid bladder vent. The second fluid, being potable water or distilled water, will transfer heat much more efficiently than the air-gap of the conventional two-walled heat exchanger.

The ductings of the first, second and third fluids are an integral piece (the second fluid bladder is a part of the integral surface as well). The phase change bladder can be plastic material. However, it can also consist of metal to be an integral part of the ducting of the three fluids. The reason for the connected ducting common to all the fluids is to achieve a large extended surface to form a highly efficient heat exchanger. The solar radiation from the first fluid will be transferred from the first fluid ducting to the second fluid through the large extended surface of the first fluid ducting which also extends to the third fluid. The second fluid is a stationary (no flow) potable water or distilled water. It will require that the extended surface of the ducting of the first fluid and the second fluid transfer the heat energy from the first fluid to the second fluid and from the second fluid to the third fluid. Example: the condensing heat transfer coefficient of the first fluid (Freon) is around 150 BTU per sq. ft. per °F. per hour. If the interior duct surface containing the first fluid is 1 sq. ft., the amount of heat transfer through the ducting for the first fluid is 150 BTU per hour from the solar collector with 1° F. temperature rise. The heat transfer rate of the second fluid (no flow) is about 20 BTU per sq. ft. per hour for the 1° F. rise. It will then require 7.5 sq. ft. of the exterior surface of the first fluid ducting to transfer heat from the first fluid to the second. If the ductings for all three fluids are connected, and submerged in the second fluid, it will make the transfer of heat from the first fluid to the second fluid highly efficient. The third fluid, city water, when flowing through the third fluid ducting has a heat transfer rate of approximately 50 BTU per sq. ft. per °F. per hour. If the third fluid ducting is 3 sq. ft., the transferred heat will be 150 BTU per °F. per hour. Once again, the exterior surface of the third ducting must be two and a half times larger to transfer the same amount of second fluid heat to the third fluid. In other words, the common ducting area serves the transfer of the no-flow second fluid from solar energy to the outlet of the third fluid.

There is a further purpose regarding the second fluid being atmospherically vented. The second fluid under sea level conditions is limited by the boiling point of 212° F. This limit also limits the first fluid vapor pressure. Under very intensive solar radiation, the vapor pressure in the solar collector could increase as a function of the collector absorber temperature. The second fluid serves as a heat sink which limits the first fluid vapor to a temperature of a few degrees higher than 212° F. Therefore, it limits the vapor pressure of the first fluid corresponding to that temperature. Also, the safety vent prevents excess pressure build-up of the first fluid.

I claim:

1. In a fluid heater assembly, the combination comprising

5

- (a) a solar collector having an inlet for a first fluid to be heated, and an outlet for the solar heated fluid,
- (b) a metallic tank for containing heat transfer second fluid,
- (c) first ducting in the tank in communication with said collector outlet to receive said heated first fluid and to transfer heat therefrom to the second fluid in the tank,
- (d) and second ducting in the tank for passing third fluid into and out of the tank, and to transfer heat from the second fluid in the tank to third fluid in the second ducting,
- (e) and including metallic structure via which heat is conducted from said first ducting to said second ducting, said first and second ducting includes generally longitudinally extending stretches in the tank contacted by said metallic structure which extends generally laterally in said second fluid,
- (f) said metallic structure comprising webbing contacting said first and second ducting and said tank,
- (g) said first and second ducting extending through said webbing the periphery of which is in heat transfer proximity to the tank wall extending about the ducting.

6

- 2. The combination of claim 1 including said first fluid which is selected from the group consisting of water and Freon.
- 3. The combination of one of claims 1 or 2 including said second fluid consisting of water.
- 4. The combination of one of claims 1 or 2 including said third fluid consisting of water.
- 5. The combination of claim 1 wherein the tank has a fill port, and an overflow port, for said second fluid.
- 6. The combination of claim 1 including a framework mounting said collector and said tank.
- 7. The combination of claim 6 wherein the tank is located above the level of the collector.
- 8. The combination of claim 1 wherein the solar collector includes a first header pipe connected in series with said inlet and a second header pipe connected with said outlet, branch piping interconnecting said header pipes, and means in at least one header pipe to cause serpentine flow to fluid between the header pipes via at least two branch pipes for each traverse between the header pipes.
- 9. The combination of claim 1 including a container in the second fluid in the tank, and a heat storing phase change material in the container.
- 10. The combination of claim 9 wherein the container is in contact with and between said first and second ducting in the tank.

* * * * *

30

35

40

45

50

55

60

65

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 4,421,100

DATED : December 20, 1983

INVENTOR(S) : Ying-Nien Yu

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the title page at (22) after Filed:, "Dec. 20, 1983"
should read -- Dec. 22, 1981 --.

Signed and Sealed this

Fourteenth **Day of** *August 1984*

[SEAL]

Attest:

GERALD J. MOSSINGHOFF

Attesting Officer

Commissioner of Patents and Trademarks



US006938680B2

(12) **United States Patent**
Garner et al.

(10) **Patent No.:** **US 6,938,680 B2**
(45) **Date of Patent:** **Sep. 6, 2005**

(54) **TOWER HEAT SINK WITH SINTERED GROOVED WICK**

(75) Inventors: **Scott D. Garner**, Lititz, PA (US);
James E. Lindemuth, Lititz, PA (US);
Jerome E. Toth, Hatboro, PA (US);
John H. Rosenfeld, Lancaster, PA (US);
Kenneth G. Minnerly, Lititz, PA (US)

(73) Assignee: **Thermal Corp.**, Stanton, DE (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 64 days.

(21) Appl. No.: **10/618,965**

(22) Filed: **Jul. 14, 2003**

(65) **Prior Publication Data**

US 2005/0011633 A1 Jan. 20, 2005

(51) **Int. Cl.**⁷ **F28D 15/00**

(52) **U.S. Cl.** **165/104.26**; 165/104.33;
165/80.4; 361/700; 257/715

(58) **Field of Search** 165/104.26, 104.21,
165/104.33, 80.4, 185; 361/699, 700; 257/714-716;
174/15.2

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,537,514 A 11/1970 Levedahl
3,598,108 A * 8/1971 Moore, Jr. 165/133
3,613,778 A 10/1971 Feldman, Jr.

(Continued)

FOREIGN PATENT DOCUMENTS

JP 60-42593 * 3/1985 165/104.26

OTHER PUBLICATIONS

Rosenfeld, J.H., "Nucleate Boiling Heat Transfer in Porous Wick Structures," ASME HTD vol. 108, *Heat Transfer Fundamentals, Design, Applications, and Operating Prob-*

lems, R.H. Shah, Ed., pp. 47-55, 1989.

Rosenfeld, J.H. and J.E. Lindemuth, "Acetone Heat Pipes for Stirling Orbiter Refrigerator/Freezer," Contract G350240J70—final report to GE Gov't. Service, Apr. 16, 1993.

McDonald, K.E., Berchowitz, D., Rosenfeld, J.H., and Lindemuth, J.E., "Stirling Refrigerator for Space Shuttle Experiments," Proc. 29th IECEC, paper 94-4179, pp. 1807-1812, 1994.

Lindemuth, J.E., "Stainless Steel/Propylene Heat Pipe Interface for Stirling Orbiter Refrigerator/Freezer," NASA LeRC final report, PO. No. C-76546-F, Apr. 21, 1998.

Rosenfeld, J.H. and Lindemuth, J.E., "Heat Transfer in Sintered Groove Heat Pipes," International Heat Pipe Conference, 1999.

Rosenfeld, J.H. and North, M.T., "Porous Media Heat Exchangers for Cooling of High-Power Optical Components," *Optical Engineering*, vol. 34, No. 2, pp. 335-341, Feb. 1995.

Rosenfeld, J.H., Toth, J.E., and Phillips, A.L., "Emerging Applications for Porous Media Heat Exchangers," Proc. Int. Conf. on Porous Media and Their Applications in Science, Eng., and Industry, Kona, HI, Jun. 16-21, 1996.

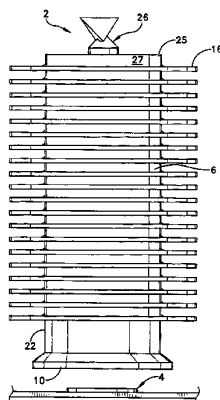
Primary Examiner—Terrell McKinnon

(74) *Attorney, Agent, or Firm*—Duane Morris LLP

(57) **ABSTRACT**

A heat pipe is provided having a tubular enclosure with an internal surface, a working fluid disposed within the enclosure, and at least one fin projecting radially outwardly from an outer surface of the tubular enclosure. The tubular enclosure is sealed at one end by a base having a grooved sintered wick disposed on at least a portion of its internally facing surface. The grooved, sintered wick comprises a plurality of individual particles having an average diameter. The grooved wick includes at least two adjacent lands that are in fluid communication with one another through a particle layer disposed between said at least two adjacent lands that comprises less than about six average particle diameters.

11 Claims, 6 Drawing Sheets



US 6,938,680 B2

Page 2

U.S. PATENT DOCUMENTS

3,675,711 A	7/1972	Bilinski et al.	5,242,644 A	9/1993	Thompson et al.
3,681,843 A	8/1972	Arcella et al.	5,253,702 A	10/1993	Davidson et al.
3,788,388 A	1/1974	Barkmann	5,268,812 A	12/1993	Conte
4,042,316 A	8/1977	Rabe	5,283,715 A	2/1994	Carlsten et al.
4,046,190 A	9/1977	Marcus et al.	5,320,866 A	6/1994	Leonard
4,118,756 A	10/1978	Nelson et al.	5,331,510 A	7/1994	Ouchi et al.
4,177,646 A	12/1979	Guadagnin et al.	5,333,470 A	8/1994	Dinh
4,231,423 A	11/1980	Haslett	5,349,237 A	9/1994	Sayka et al.
4,274,479 A *	6/1981	Eastman 165/104.26	5,408,128 A	4/1995	Furnival
4,279,479 A	7/1981	Schrier	5,409,055 A	4/1995	Tanaka et al.
4,327,752 A	5/1982	Hickel	5,412,535 A *	5/1995	Chao et al. 361/700
4,354,482 A	10/1982	Beisecker	5,522,455 A	6/1996	Brown et al.
4,361,133 A	11/1982	Bonnema	5,549,394 A	8/1996	Nowak et al.
4,365,851 A	12/1982	Andres et al.	5,582,242 A *	12/1996	Hamburgen et al. ... 165/104.21
4,366,526 A	12/1982	Lijoi et al.	5,632,158 A *	5/1997	Tajima 62/259.2
4,374,528 A	2/1983	Tittert	5,642,776 A *	7/1997	Meyer et al. 165/104.26
4,382,448 A	5/1983	Tittert	5,664,890 A	9/1997	Nowak et al.
4,489,777 A	12/1984	Del Bagno et al.	5,711,816 A	1/1998	Kirlin et al.
4,503,483 A	3/1985	Basiulis	5,769,154 A	6/1998	Adkins et al.
4,557,413 A	12/1985	Lewis et al.	5,826,645 A	10/1998	Meyer, IV et al.
4,616,699 A	10/1986	Grote	5,847,925 A	12/1998	Progl et al.
4,641,404 A	2/1987	Seydel et al.	5,880,524 A	3/1999	Xie
4,697,205 A	9/1987	Eastman	5,883,426 A	3/1999	Tokuno et al.
4,748,314 A	5/1988	Desage	5,947,193 A	9/1999	Adkins et al.
4,765,396 A	8/1988	Seidenberg	5,950,710 A	9/1999	Liu
4,777,561 A	10/1988	Murphy et al.	6,041,211 A	3/2000	Hobson et al.
4,807,697 A	2/1989	Gernert et al.	6,055,157 A	4/2000	Bartilson
4,819,719 A	4/1989	Grote et al.	6,056,044 A	5/2000	Benson et al.
4,830,097 A	5/1989	Tanzer	6,082,443 A	7/2000	Yamamoto et al.
4,840,224 A	6/1989	Dietzsch	6,148,906 A	11/2000	Li et al.
4,865,729 A	9/1989	Saxena et al.	6,154,364 A	11/2000	Girrens et al.
4,880,052 A	11/1989	Meyer, IV et al.	6,158,502 A	12/2000	Thomas
4,883,116 A	11/1989	Seidenberg et al.	6,167,948 B1	1/2001	Thomas
4,885,129 A	12/1989	Leonard et al.	6,169,852 B1	1/2001	Liao et al.
4,912,548 A	3/1990	Shanker et al.	6,227,287 B1 *	5/2001	Tanaka et al. 165/80.4
4,921,041 A	5/1990	Akachi	6,230,407 B1	5/2001	Akutsu
4,929,414 A	5/1990	Leonard et al.	6,239,350 B1	5/2001	Sievers et al.
4,931,905 A	6/1990	Cirrito et al.	6,256,201 B1	7/2001	Ikeda et al.
4,960,202 A	10/1990	Rice et al.	6,293,333 B1	9/2001	Ponnappan et al.
4,982,274 A	1/1991	Murase et al.	6,302,192 B1	10/2001	Dussinger et al.
5,059,496 A	10/1991	Sindorf	6,303,081 B1	10/2001	Mink et al.
5,076,352 A	12/1991	Rosenfeld et al.	6,382,309 B1	5/2002	Kroliczek et al.
5,101,560 A	4/1992	Leonard et al.	6,388,882 B1	5/2002	Hoover et al.
5,103,897 A	4/1992	Cullimore et al.	6,397,935 B1	6/2002	Yamamoto et al.
5,148,440 A	9/1992	Duncan	6,418,017 B1	7/2002	Patel et al.
5,160,252 A	11/1992	Edwards	6,536,510 B2 *	3/2003	Khrustalev et al. 165/104.33
5,200,248 A	4/1993	Thompson et al.	6,725,909 B1 *	4/2004	Luo 165/104.21
5,219,020 A	6/1993	Akachi	6,793,009 B1 *	9/2004	Sarraf 165/104.33

* cited by examiner

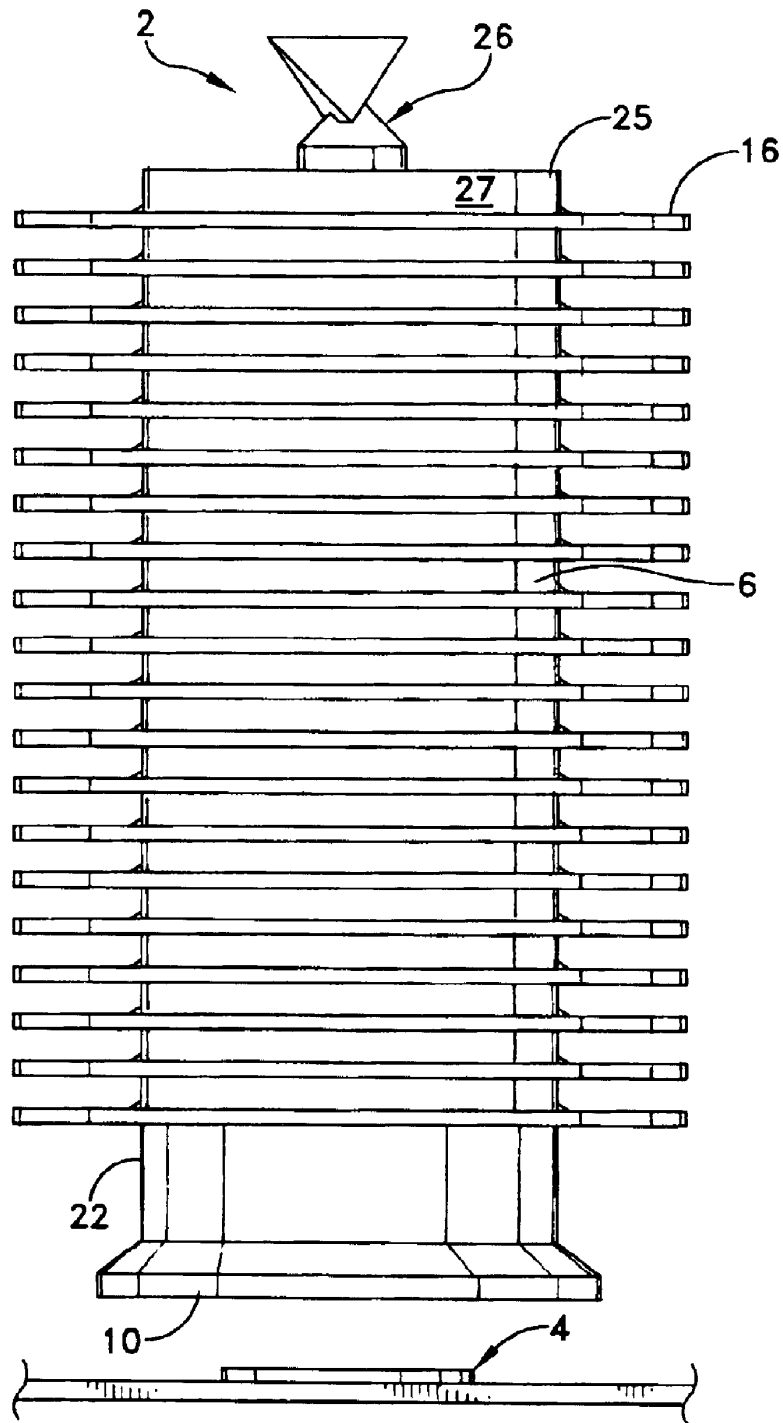


FIG. 1

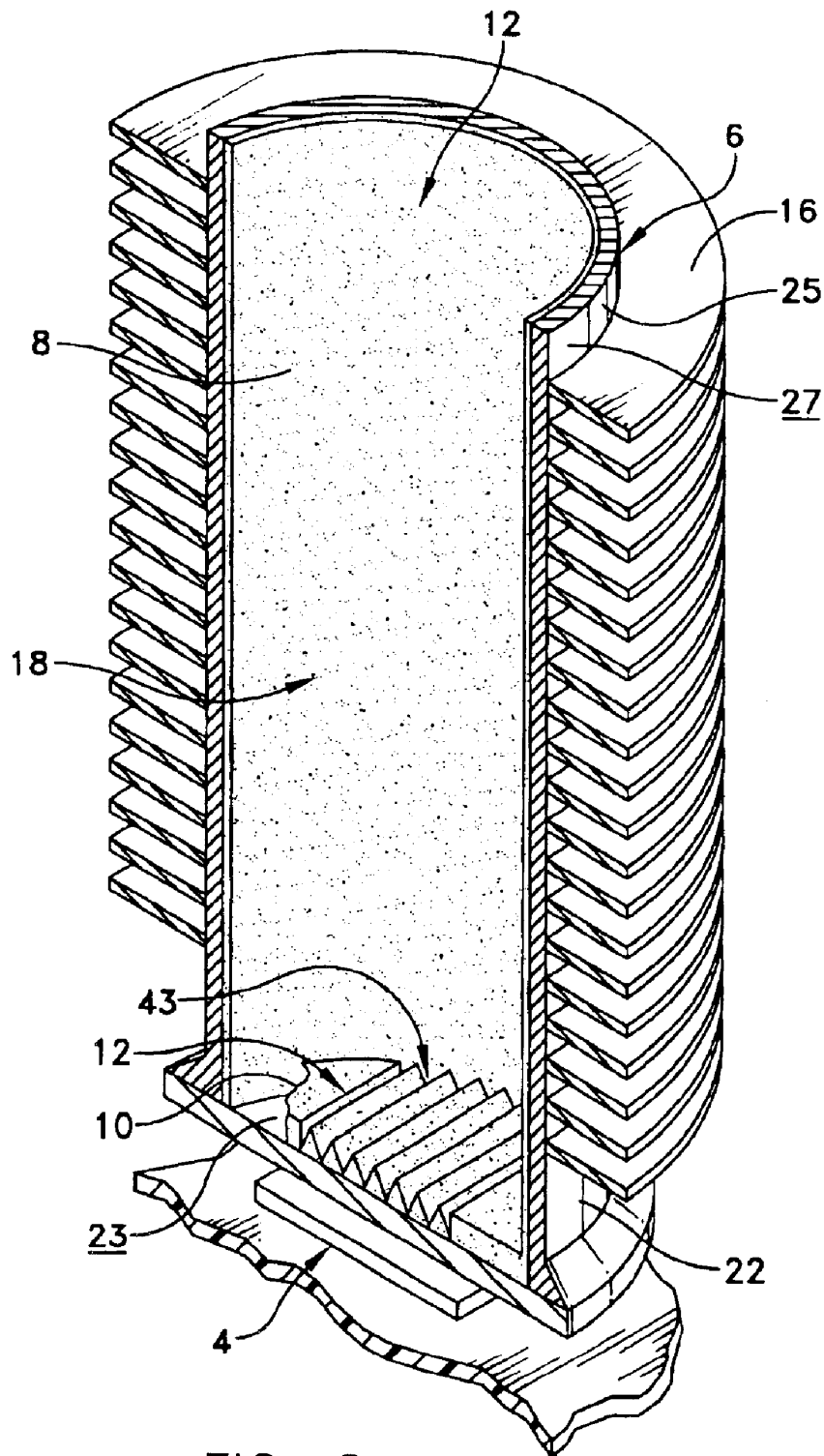


FIG. 2

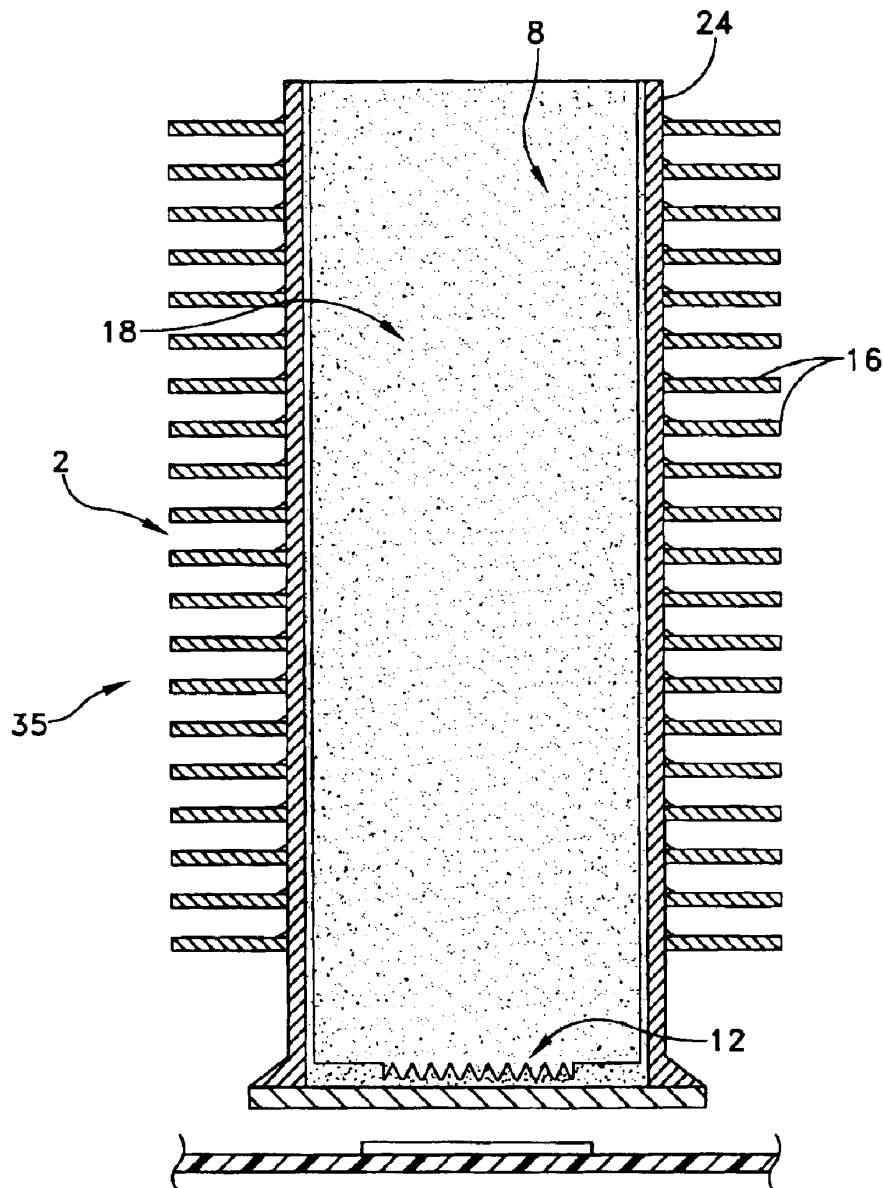


FIG. 3

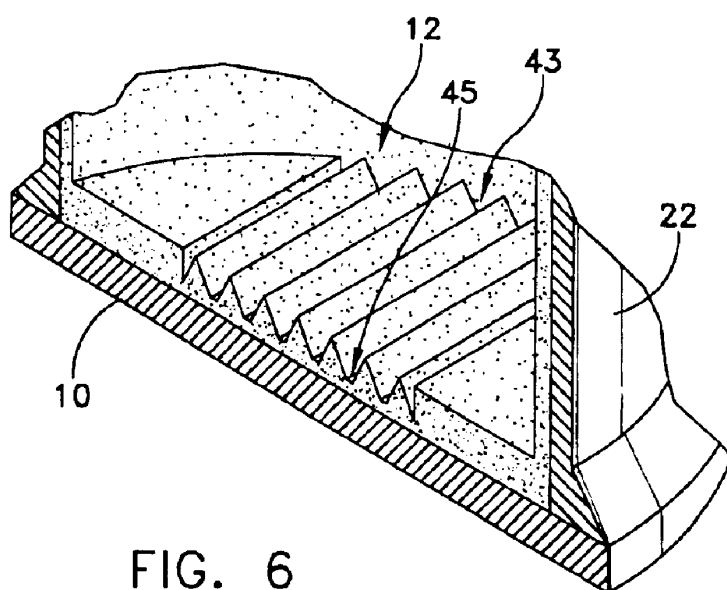


FIG. 6

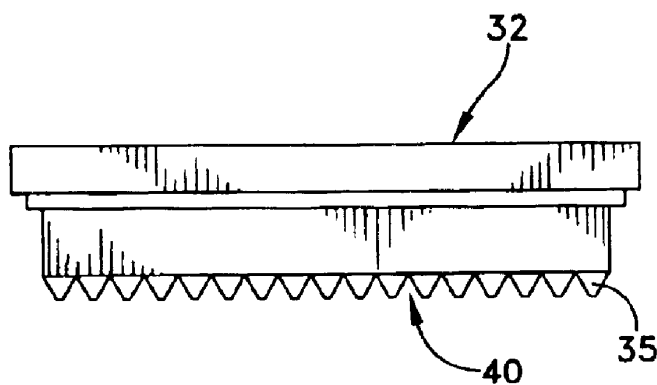


FIG. 7

1

TOWER HEAT SINK WITH SINTERED GROOVED WICK

FIELD OF THE INVENTION

The present invention generally relates to the management of thermal energy generated by electronic systems, and more particularly to a heat pipe-related tower heat sink for efficiently and cost effectively routing and controlling the thermal energy generated by various components of an electronic system.

BACKGROUND OF THE INVENTION

Semiconductors are continuously diminishing in size. Corresponding to this size reduction is an increase in the power densities of semiconductors. This, in turn, creates heat proliferation problems which must be resolved because excessive heat will degrade semiconductor performance. Heat pipes are known in the art for both transferring and spreading heat that is generated by electronic devices.

Heat pipes use successive evaporation and condensation of a working fluid to transport thermal energy from a heat source to a heat sink. Heat pipes can transport very large amounts of thermal energy in a vaporized working fluid, because most working fluids have a high heat of vaporization. Further, the thermal energy can be transported over relatively small temperature differences between the heat source and the heat sink. Heat pipes generally use capillary forces created by a porous wick to return condensed working fluid, from a heat pipe condenser section (where transported thermal energy is given up at the heat sink) to an evaporator section (where the thermal energy to be transported is absorbed from the heat source).

Heat pipe wicks are typically made by wrapping metal screening of felt metal around a cylindrically shaped mandrel, inserting the mandrel and wrapped wick inside a heat pipe container and then removing the mandrel. Wicks have also been formed by depositing a metal powder onto the interior surfaces of the heat pipe and then sintering the powder to create a very large number of interstitial capillaries. Typical heat pipe wicks are particularly susceptible to developing hot spots where the liquid condensate being wicked back to the evaporator section boils away and impedes or blocks liquid movement. Heat spreader heat pipes can help improve heat rejection from integrated circuits. A heat spreader is a thin substrate that absorbs the thermal energy generated by, e.g., a semiconductor device, and spreads the energy over a large surface of a heat sink.

Ideally, a wick structure should be thin enough that the conduction delta-T is sufficiently small to prevent boiling from initiating. Thin wicks, however, have not been thought to have sufficient cross-sectional area to transport the large amounts of liquid required to dissipate any significant amount of power. For example, the patent of G. Y. Eastman, U.S. Pat. No. 4,274,479, concerns a heat pipe capillary wick structure that is fabricated from sintered metal, and formed with longitudinal grooves on its interior surface. The Eastman wick grooves provide longitudinal capillary pumping while the sintered wick provides a high capillary pressure to fill the grooves and assure effective circumferential distribution of the heat transfer liquid. Eastman describes grooved structures generally as having "lands" and "grooves or channels". The lands are the material between the grooves or channels. The sides of the lands define the width of the grooves. Thus, the land height is also the groove depth. Eastman also states that the prior art consists of grooved

2

structures in which the lands are solid material, integral with the casing wall, and the grooves are made by various machining, chemical milling or extrusion processes.

Significantly, Eastman suggests that in order to optimize heat pipe performance, his lands and grooves must be sufficient in size to maintain a continuous layer of fluid within a relatively thick band of sintered powder connecting the lands and grooves such that a reservoir of working fluid exists at the bottom of each groove. Thus, Eastman requires his grooves to be blocked at their respective ends to assure that the capillary pumping pressure within the groove is determined by its narrowest width at the vapor liquid interface. In other words, Eastman suggests that these wicks do not have sufficient cross-sectional area to transport the relatively large amounts of working fluid that is required to dissipate a significant amount of thermal energy.

SUMMARY OF THE INVENTION

The present invention provides a tower heat pipe comprising a tubular enclosure having an internal surface at least partially covered with a wick, a working fluid disposed within the enclosure, and at least one fin projecting radially outwardly from an outer surface of the tubular enclosure. The tubular enclosure is sealed at one end by a base having a grooved sintered wick disposed on at least a portion of its internal surface. The grooved, sintered wick comprises a plurality of individual particles having an average diameter. The grooved wick includes at least two lands that are in fluid communication with one another through a particle layer disposed between the at least two lands that comprises less than about six average particle diameters.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other features and advantages of the present invention will be more fully disclosed in, or rendered obvious by, the following detailed description of the preferred embodiment of the invention, which is to be considered together with the accompanying drawings wherein like numbers refer to like parts and further wherein:

FIG. 1 is a front elevational view of a tower heat pipe formed in accordance with the present invention;

FIG. 2 is a cross-sectional perspective view of the tower heat pipe shown in FIG. 1;

FIG. 3 is an elevational cross-sectional view of the tower heat pipe shown in FIGS. 1 and 2;

FIG. 4 is a broken-away, enlarged view of a portion of a base-wick shown in FIGS. 2 and 3;

FIG. 5 is a significantly enlarged view of a portion of a groove-wick disposed at the bottom of the heat pipe of FIGS. 1-3, showing an extremely thin wick structure disposed between individual lands of the wick;

FIG. 6 is a broken-away end portion of a base-wick and base formed in accordance with the present invention; and

FIG. 7 is a perspective view of a typical mandrel used to form a base-wick in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

This description of preferred embodiments is intended to be read in connection with the accompanying drawings, which are to be considered part of the entire written description of this invention. The drawing figures are not necessarily to scale and certain features of the invention may be shown exaggerated in scale or in somewhat schematic form

3

in the interest of clarity and conciseness. In the description, relative terms such as "horizontal," "vertical," "up," "down," "top" and "bottom" as well as derivatives thereof (e.g., "horizontally," "downwardly," "upwardly," etc.) should be construed to refer to the orientation as then described or as shown in the drawing figure under discussion. These relative terms are for convenience of description and normally are not intended to require a particular orientation. Terms including "inwardly" versus "outwardly," "longitudinal" versus "lateral" and the like are to be interpreted relative to one another or relative to an axis of elongation, or an axis or center of rotation, as appropriate. Terms concerning attachments, coupling and the like, such as "connected" and "interconnected," refer to a relationship wherein structures are secured or attached to one another either directly or indirectly through intervening structures, as well as both movable or rigid attachments or relationships, unless expressly described otherwise. The term "operatively connected" is such an attachment, coupling or connection that allows the pertinent structures to operate as intended by virtue of that relationship. In the claims, means-plus-function clauses are intended to cover the structures described, suggested, or rendered obvious by the written description or drawings for performing the recited function, including not only structural equivalents but also equivalent structures.

Referring to FIGS. 1 and 2, the present invention comprises a tower heat pipe heat 2 that is sized and shaped to transfer thermal energy generated by at least one thermal energy source, e.g., a semiconductor device 4 that is thermally engaged with a portion of tower heat pipe 2. Heat pipe 2 includes a body 6, a body-wick 8, a base 10, a base-wick 12, and fins 16. More particularly, body 6 comprises a cylindrical tube formed from a highly thermally conductive metal, e.g., copper or its alloys, nickel or its alloys (such as monel an alloy of nickel and copper) could be incorporated into the structure with no significant changes in design or fabrication method. A vapor space is defined by a central passageway 18 extending along the longitudinal axis of body 6. Body 6 includes a bottom end 22 and a top end 25. Bottom end 22 is hermetically sealed to an inner surface 23 of base 10. Top end 25 is pinched off or otherwise sealed at a fill tube 26 during construction. Fins 16 project radially outwardly from outer surface 27 of body 6. Fins 16 may be formed from any thermally conductive material, such as copper, aluminum, or their alloys.

Referring to FIG. 2, body-wick 8 is preferably formed from a sintered copper powder or the like, that is distributed throughout the inner surface of body 6 that defines central passageway 18. Although not preferred, body-wick 8 may also comprise adjacent layers of screening or a sintered powder structure with interstices between the particles of powder, having an average thickness of about 0.1 mm to 1.0 mm. Additionally, central passageway 18 may be devoid of some or all of body-wick 8, particularly in gravity-aided embodiments of the invention.

Referring to FIGS. 2-6, base-wick 12 is located on inner surface 23 of base 10, and is often formed from a metal powder 30 that is sintered in place around a shaped mandrel 32 (FIG. 7) to form a sintered groove structure. Lands 35 of mandrel 32 form grooves 37 of finished base-wick 12, and grooves 40 of mandrel 32 form lands 42 of base-wick 12. Each land 42 is formed as an inverted, substantially "V"-shaped or pyramidal protrusion having sloped side walls 44a, 44b, and is spaced-apart from adjacent lands. Grooves 37 separate lands 42 and are arranged in substantially parallel rows that extend through a portion of inner surface

4

23. The terminal portions 43 of grooves 37 may be disposed adjacent to the inner surface of bottom end 22 of body 6, or may be spaced away from body 6.

Advantageously, a relatively thin layer of sintered powder 30 is deposited upon inner surface 23 of base 10 so as to form a groove-wick 45 at the bottom of each groove 37, and between spaced-apart lands 42. When base-wick 12 is arranged in spaced-away relation to the inner surface of bottom end 22 of body 6, groove-wick 45 extends between terminal portions 43 of grooves 37 and the inner surface of body 6. Sintered powder 30 may be selected from any of the materials having high thermal conductivity and that are suitable for fabrication into porous structures, e.g., carbon, tungsten, copper, aluminum, magnesium, nickel, gold, silver, aluminum oxide, beryllium oxide, or the like, and may comprise either substantially spherical, arbitrary or regular polygonal, or filament-shaped particles of varying cross-sectional shape. For example, sintered copper powder 30 is deposited between lands 42 (and on the portion of base 10 that surrounds base-wick 12) such that groove-wick 45 comprises an average thickness of about one to six average copper particle diameters (approximately 0.005 millimeters to 0.5 millimeters, preferably, in the range from about 0.05 millimeters to about 0.25 millimeters) when deposited over substantially all of inner surface 23 of base 10, and in the space between sloped side walls 44a, 44b at the bottom of lands 42. Of course, other wick materials, such as, aluminum-silicon-carbide or copper-silicon-carbide may be used with similar effect.

Significantly groove-wick 45 is formed so as to be thin enough that the conduction delta-T is small enough to prevent boiling from initiating at the interface between inner surface 23 and the sintered powder forming the wick. Groove-wick 45 is an extremely thin wick structure that is fed by spaced lands 42 which provide the required cross-sectional area to maintain effective working fluid flow. In cross-section, groove-wick 45 comprises an optimum design when it comprises the largest possible (limited by capillary limitations) flat area between lands 42. This area should have a thickness of, e.g., only one to six copper powder particles. The thinner groove-wick 45 is, the better performance within realistic fabrication constraints, as long as the surface area of inner surface 23 has at least one layer of copper particles. This thin wick area takes advantage of the enhanced evaporative surface area of the groove-wick layer, by limiting the thickness of groove-wick 45 to no more than a few powder particles. This structure has been found to circumvent the thermal conduction limitations associated with the prior art.

It is to be understood that the present invention is by no means limited only to the particular constructions herein disclosed and shown in the drawings, but also comprises any modifications or equivalents within the scope of the claims.

What is claimed is:

1. A tower heat pipe comprising:

a tube having an internal surface at least partially covered with a wick, a working fluid disposed within said tube, a sealed first end, and at least one fin projecting radially outwardly from an outer surface of said tube;

a base sealingly fixed to a second end of said tube, and having a grooved sintered wick disposed on at least a portion of an internal surface;

said grooved sintered wick comprising a plurality of individual particles which together yield an average particle diameter, and including at least two lands that are in fluid communication with one another through a

5

particle layer disposed between said at least two lands wherein said particle layer comprises at least one dimension that is no more than about six average particle diameters.

2. A tower heat pipe according to claim 1 wherein said particle layer comprises a thickness that is about three average particle diameters.

3. A tower heat pipe according to claim 1 wherein said particles are formed substantially of copper.

4. A tower heat pipe according to claim 1 wherein said six average particle diameters is within a range from about 0.05 millimeters to about 0.25 millimeters.

5. A heat pipe comprising:

a tubular enclosure having an internal surface covered by a wick and sealed at a first end;

a base sealing fixed to a second end of said enclosure so as to form an internal surface within said enclosure;

a working fluid disposed within said enclosure;

at least one fin projecting radially outwardly from an outer surface of said tubular enclosure; and

a grooved sintered wick disposed upon said internal surface formed by said base, said grooved sintered wick comprising a plurality of individual particles which together yield an average particle diameter, and including at least two lands that are in fluid communication with one another through a particle layer disposed between said at least two lands wherein said particle layer comprises at least one dimension that is no more than about six average particle diameters.

6. A heat pipe according to claim 5 wherein said particle layer comprises a thickness that is less than about three average particle diameters.

6

7. A heat pipe according to claim 5 wherein said particles are formed substantially of copper.

8. A heat pipe according to claim 5 wherein six average particle diameters is within a range from about 0.005 millimeters to about 0.5 millimeters.

9. A heat pipe according to claim 5 wherein said particle layer extends between a terminal portion of said lands and adjacent portions of said enclosure on said internal surface.

10. A heat pipe according to claim 5 wherein said particle layer is formed from a material selected from the group consisting of carbon, tungsten, copper, aluminum, magnesium, nickel, gold, silver, aluminum oxide, and beryllium oxide.

11. A tower heat pipe comprising:

a tube having an internal surface, a working fluid disposed within said tube, a sealed first end, and at least one fin projecting radially outwardly from an outer surface of said tube;

a base sealingly fixed to a second end of said tube, and having a grooved sintered wick disposed on at least a portion of an internal surface;

said grooved sintered wick comprising a plurality of individual particles which together yield an average particle diameter, and including at least two lands that are in fluid communication with one another through a particle layer disposed between said at least two lands wherein said particle layer comprises at least one dimension that is no more than about six average particle diameters.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,938,680 B2
DATED : September 6, 2005
INVENTOR(S) : Garner et al.

Page 1 of 1

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 5,

Line 16, delete "sealing" and insert -- sealingly --.

Signed and Sealed this

Twenty-ninth Day of November, 2005

A handwritten signature in black ink, reading "Jon W. Dudas". The signature is stylized with a large, looped initial "J" and a cursive "Dudas".

JON W. DUDAS
Director of the United States Patent and Trademark Office

students, operations engineers, and mechanical electronic packaging industry grasp the principles of heat pipes. Packed with examples and design background and historical development of the fundamental operating principles and limitations of heat pipes.

of the governing physical phenomena involved, features extensive coverage of:

fluids, their behavior in heat pipes, and associated technologies and manufacturing considerations electrical and mechanical systems classifications, including rotating and revolving, the conduction heat pipes, as well as thermal

information and guidance you need to increase your productive devices and to begin to apply them to the thermal systems and components.

Professor and Head of the Department of Texas A&M University, where he received his PhD. He has been Program Director of the National Thermal Transport and Thermal Processing Program at NASA's Johnson Space Center.



Group
10158-0012
Toronto • Singapore

An Introduction to HEAT PIPES



HEAT PIPES

Modeling, Testing, and Applications

G.P. Peterson

Wiley Series in Thermal Management of Microelectronic & Electronic Systems
Allan D. Kraus and Avram Bar-Cohen, Series Editors

AN INTRODUCTION TO HEAT PIPES

Modeling, Testing, and
Applications

G. P. PETERSON

*Department of Mechanical Engineering
Texas A&M University
College Station, Texas*



A Wiley-Interscience Publication

JOHN WILEY & SONS, INC.

New York / Chichester / Brisbane / Toronto / Singapore

To Valerie—Thank you.

This text is printed on acid-free paper.

Copyright © 1994 by John Wiley & Sons, Inc.

All rights reserved. Published simultaneously in Canada.

Reproduction or translation of any part of this work beyond that permitted by Section 107 or 108 of the 1976 United States Copyright Act without the permission of the copyright owner is unlawful. Requests for permission or further information should be addressed to the Permissions Department, John Wiley & Sons, Inc., 605 Third Avenue, New York, NY 10158-0012.

Library of Congress Cataloging in Publication Data:

Peterson, G. P. (George P.)

An introduction to heat pipes : modeling, testing, and applications / G. P. Peterson.

p. cm.

Includes bibliographical references.

ISBN 0-471-30512-X (alk. paper)

1. Heat pipes. I. Title.

TJ264.P48 1994

621.402'5—dc20

93-51014

Printed in the United States of America

10 9 8 7 6 5 4 3 2 1

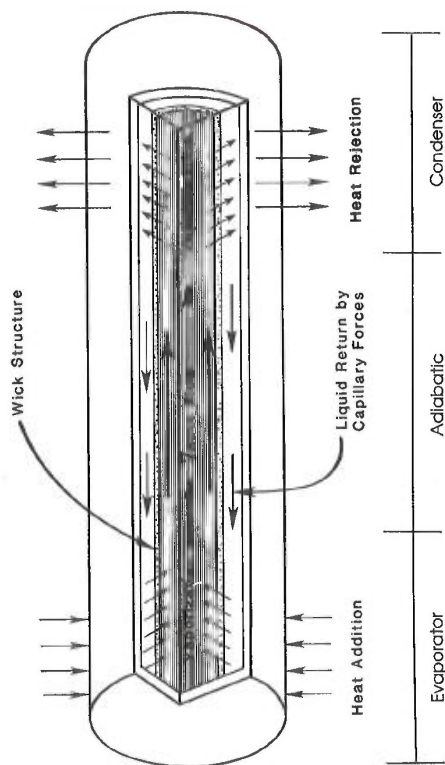


Figure 1.3 Typical heat pipe construction and operation.

vehicle through which, and provides the mechanism by which, the working fluid is returned from the condenser to the evaporator and also ensures that the working fluid is evenly distributed over the evaporator surface. Figure 1.4 illustrates several common wicking structures presently in use, along with several more advanced concepts under development. In order to provide a flow path with low flow resistance through which the liquid can be returned from the condenser to the evaporator, an open porous structure with a high permeability is desirable. However, to increase the capillary pumping pressure, a small pore size is necessary. Solutions to this apparent dichotomy can be achieved through the use of a nonhomogeneous wick made of several different materials or through composite wicking structures similar to those shown in Fig. 1.4b.

Udell and Jennings (1984) proposed and formulated a model for a heat pipe with a wick consisting of porous media of two different permeabilities oriented parallel to the direction of the axial heat flux. This wick structure provided a large pore size in the center of the wick to reduce the viscous pressure drop associated with the axial liquid flow and a smaller size pore to enhance the capillary pressure occurring at the liquid-vapor interface in the evaporator. Current composite wicking structures utilize the same approach with the capillary pumping and axial fluid transport being handled independently. In addition to fulfilling this dual purpose, several of the advanced wick designs illustrated separate the liquid and vapor flow to reduce the viscous shear force that occurs during the countercurrent, liquid-vapor flow.

Because the basis for operation of a heat pipe is the vaporization and condensation of the working fluid, selection of a suitable fluid is an

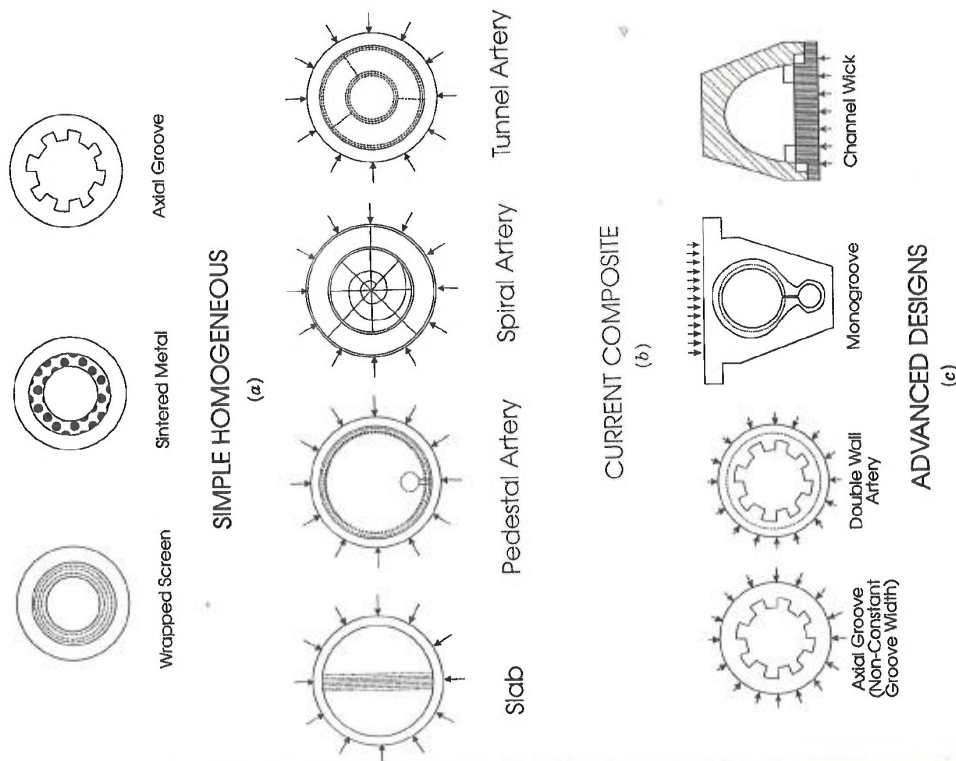


Figure 1.4 Typical heat pipe wicking configurations and structures.

important factor in the design and manufacture of heat pipes. Care must be taken to ensure that the operating temperature range is adequate for the application. While most applications involving the use of heat pipes in the thermal control of electronic devices and systems require the use of a working fluid with boiling temperatures between 250 and 375 K, both cryogenic heat pipes (operating in the 5 to 100 K temperature range) and liquid metal heat pipes (operating in the 750 to 5000 K temperature range) have been developed and used. Figure 1.5 illustrates the possible working

CERTIFICATE OF SERVICE
(Fed. R. Civ. P. 5)

I am a citizen of the United States and a resident of the State of California. I am employed in Santa Clara County, State of California. I am over the age of eighteen years, and not a party to the within action. My business address is Cooley LLP, 3175 Hanover Street, Palo Alto, California 94304-1130. On the date set forth below, I served the documents described below in the manner described below:

**SUPPLEMENTAL DECLARATION OF DR. HIMANSHU POKHARNA IN RESPONSE
TO DECLARATION OF MR. NELSON GERNERT**

- ☐ (BY U.S. MAIL) I am personally and readily familiar with the business practice of Cooley LLP for collection and processing of correspondence for mailing with the United States Postal Service, and I caused such envelope(s) with postage thereon fully prepaid to be placed in the United States Postal Service at Palo Alto, California.
- ☐ (BY MESSENGER SERVICE) by consigning the document(s) to an authorized courier and/or process server for hand delivery on this date.
- ☐ (BY FACSIMILE) I am personally and readily familiar with the business practice of Cooley LLP for collection and processing of document(s) to be transmitted by facsimile and I caused such document(s) on this date to be transmitted by facsimile to the offices of addressee(s) at the numbers listed below.
- ☐ (BY OVERNIGHT MAIL) I am personally and readily familiar with the business practice of Cooley LLP for collection and processing of correspondence for overnight delivery, and I caused such document(s) described herein to be deposited for delivery to a facility regularly maintained by _____ for overnight delivery.
- ☒ (BY ELECTRONIC MAIL) I am personally and readily familiar with the business practice of Cooley LLP for the preparation and processing of documents in portable document format (PDF) for e-mailing, and I caused said documents to be prepared in PDF and then served by electronic mail to the parties listed below.

on the following part(ies) in this action:

Frank L. Bernstein
Singularity LLP
555 Twin Dolphin Drive, Suite 610
Redwood Shores, CA 94065
fbernstein@ipsingularity.com

Jonathan H. Margolies
Michael Best & Friedrich LLP
100 E. Wisconsin Avenue, Suite 3300

1 Milwaukee, WI 53202-4108
2 jhmargolies@michaelbest.com

3 J. Donald Best
4 Kenneth M. Albridge III
5 Michael Best & Friedrich LLP
6 One South Pinckney Street, Suite 700
7 Madison, WI 53703
8 jdbest@michaelbest.com
9 kmalbridge@michaelbest.com

10 Executed on July 27, 2018 in Palo Alto, California.

11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28

/s/ *Kyle D. Chen*
Kyle D. Chen

182159637